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PRE-CAMBRIAN GEOLOGY AND MINERAL RESOURCES OF THE DELAWARE WATER GAP AND EASTON QUADRANGLES, NEW JERSEY AND PENNSYLVANIA

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PRE-CAMBRIAN GEOLOGY AND MINERAL RESOURCES OF THE DELAWARE WATER GAP AND EASTON QUADRANGLES, NEW JERSEY AND PENNSYLVANIA

By W. S. Bayley

ABSTRACT

The area whose geology and economic products are described covers a belt 8 to 10 miles wide extending from Buttzville, N. J., southwestward about 16 miles.

Although the first field work by the Geological Survey was done in 1906, in anticipation of the publication of a folio of the geologic atlas on the area, supplementary studies were carried on in 1926, 1929, and 1931. In the 25-year interval there were many changes, but in view of the present renewed activity in the iron industry and the fact that this report locates and describes many old mines at which conditions are now obscured, the manuscript has been left essentially in its original form because it furnishes valuable information concerning old workings which it may be desired to reopen. Moreover, it affords an excellent record of scientific details of the local pre-Cambrian geology and of the ore deposits.

Topography and areal geology.—The northern part of this area is crossed by a series of ridges representing a part of the Highland belt in New Jersey and Pennsylvania, and the southern part is intersected in a general southerly direction by the Delaware River. Pre-Cambrian rocks, mainly gneisses, compose the ridges, between which are Paleozoic limestone and shale, which also form the wide valley bordering the ridges on the north. South of the ridges is the Piedmont Plateau, underlain by conglomerate, sandstone, and shale of the Newark group except in a few narrow strips at the bases of the ridges, where Paleozoic beds crop out. In this region there is shown more clearly than elsewhere in the Highlands the series of metamorphic rocks which are intruded by the predominant gneisses of the New Jersey Highlands.

Pegmatites occur throughout the region in association with gneiss, limestone, and other rocks. Although commonly occurring in sheets parallel to the associated limestone and gneiss, some pegmatite dikes cut across the structure of these rocks, indicating that the pegmatites are younger. The principal minerals of the pegmatites are the same as those in the gneisses, that is, quartz, microcline, microperthite, oligoclase, hornblende, pyroxene, biotite, and in places magnetite, graphite, and muscovite. Hornblende is abundant in dikes that are associated with magnetite ores. In some of the pegmatite bodies the proportion of magnetite is so great that the rock has been mined as lean iron ore.

Mineral resources.—The principal economic products obtained from the pre-Cambrian rocks of this area are magnetic iron ore, marble used in the manu-

facture of portland cement, and serpentine talcose rocks used for paper filler, stucco, terrazzo, and roofing. In the lower part of the Paleozoic beds near their contact with the pre-Cambrian, limonite has been mined for iron ore and paint material, and limestone and shale are used as cement material. Other products of the region are hematite, zinc ore, kaolin, asbestos, mica, and building stone. At present, most of the mines and many of the quarries that were active 25 to 30 years ago are no longer being worked, but the Washington magnetite mine has been operated at intervals since then. The area most promising for future development appears to be in the vicinity of West Portal, N. J., where two veins 60 feet apart extend with minor interruptions a distance of 3 miles.

The magnetite deposits occur as richly magnetiferous pegmatites, as layers or lenses in the Franklin limestone, and as interleaved layers in the Byram and Losee gneisses and the schists of the Pickering gneiss, the ore bodies in the gneisses and schists being by far the most valuable. The richer ore bodies are pod-shaped lenses, with their longitudinal planes parallel to the dip of the foliation in the neighboring gneisses and their longer axes conformable with the pitch of the rock structure. Usually several lenses lie in the same plane, all pitching and dipping in the same direction.

The principal components of the ores in the gneisses, in addition to magnetite, are hornblende, pyroxene, quartz, plagioclase, and apatite. Calcite and pyrite, where present, are later introductions as veins cutting the ore. As the proportion of these minerals varies, so does the availability of the material as commercial ore. For example, apatite varies widely, independently of the other components. Where it is present in small quantity the ore may be within the Bessemer limits of phosphorus content; elsewhere its proportion may be so high as to preclude the use of the material as a source of iron. From some mines ore has been obtained nearly rich enough to be used directly as a commercial product, but that from most mines has had to be cobbed or washed. Ores from veins in the gneisses usually contain too high a percentage of phosphorus to be of Bessemer grade. Titanium is also usually high, but manganese and water are low. The ores from the limestones, however, usually contain little phosphorus and titanium, but manganese and water are usually high. In typical magnetic ores the iron ranged between 47.6 and 60.4 percent, manganese between 0.02 and 4.35 percent, silica between 7.8 and 15.70 percent, alumina between 1.29 and 1.35 percent, lime between 1.26 and 1.7 percent, and phosphorus between 0.09 and 0.49 percent.

Limonite mining was formerly an important industry in this area but now only a small quantity is being produced for use in mineral paint. This ore is present in the Kittatinny limestone, usually near its base, where it is in contact with the underlying Hardyston quartzite, or with gneiss, in irregular layers or flat lenses following the general direction of contact planes between the gneiss and the Paleozoic, and it is found also in fault zones. The nodular masses and small fragments of compact limonite are so mixed with different proportions of ocherous earth, sand, and barren rock that the material has to be hand-picked or washed. Shipments appear to have been of the ordinary grade, carrying between 35 and 57 percent of iron and as much as 1.6 percent of phosphorus.

Origin of the magnetite.—The magnetites associated with gneisses and schists are believed to be of magmatic origin, the source of the material having been deep-seated molten magmas, which upon being intruded into the overlying rocks solidified as various gneisses. After partial cooling the gneisses were in turn intruded by ferruginous portions of the source magma, producing pegmatites and hornblende-augite masses, and these intrusions were later enriched by iron-bearing solutions or vapors that originated in the same subterranean source. In their transit to the surface these solutions or vapors deposited additional magnetite in the intruded ferruginous rocks, perhaps replacing some of the earlier minerals, and formed the ore lenses that now constitute the ore bodies.

The magnetite bodies in the limestone are probably the result of the two processes outlined in connection with the ores in the gneisses and schists.

Views of other authors as to the origin of these ores are also given with brief discussion of various points of divergence.

Origin of the limonite.—The limonite is believed to correspond in origin to that found in similar geologic associations in certain Southern Appalachian localities. Here the principal source of the iron is thought to have been the limestone and shale associated with the ore bodies and the rocks that originally overlay them but that have disappeared as the result of erosion. Also, a small quantity of iron probably was furnished by pyrite occurring in adjacent gneisses and their included magnetite. Ferruginous solutions that contain sulphates or carbonates on mingling with alkaline waters resulting from solution of limestone or on coming into contact with the limestone itself would tend to precipitate iron hydroxide or possibly iron carbonate, which would alter to the hydroxide.

There is in these New Jersey-Pennsylvania deposits a significant resemblance to the association of limonite and kaolin observed by Loughlin at the Dragon iron mine in the Tintic district, Utah, and of limonite, kaolin, and zinc carbonate at Leadville, Colo.

The suggestion by H. M. Chance that all limonite deposits in the eastern United States are gossans due to oxidation of pyrite is discussed and shown not to be wholly applicable to the deposits here described.

INTRODUCTION

The area discussed in this report occupies a belt of country about 8 miles wide in the Easton and Delaware Water Gap quadrangles that extends from Buttzville, N. J., southwestward to the west side of the Easton quadrangle (fig. 1), a distance of about 16 miles. It is crossed in a northeasterly direction by a series of ridges forming a part of the Highland belt in New Jersey and Pennsylvania and is intersected in a general southerly direction by the Delaware River (fig. 2). The largest settlements in the area are Easton, Pa., and Phillipsburg, N. J. Belvidere, N. J., is at its northern border. The long, narrow ridges that are a conspicuous feature of the topography of the belt are composed of pre-Cambrian rocks, and the valleys between them are underlain by Paleozoic beds, as is also the wide valley bordering the ridges on the north. South of the ridges is the Piedmont Plateau. This is underlain by the beds of the Newark group, except in a few narrow strips at the bases of the ridges, where Paleozoic beds crop out.

This paper deals with the geology and economic products of the pre-Cambrian rocks and with the iron ores of the district, both those that occur in the pre-Cambrian rocks and those that occur in the Paleozoic beds.

The area is of special interest because it exhibits more clearly than anywhere else in the Highlands the series of metamorphic rocks into which the predominant gneisses of the New Jersey Highlands were intruded.

Most of the field work upon which this report is based was done about 1906, in anticipation of the publication of a folio of the Geologic Atlas on the area. The long delay in publication suggested the issuance of an account of the pre-Cambrian geology and economic

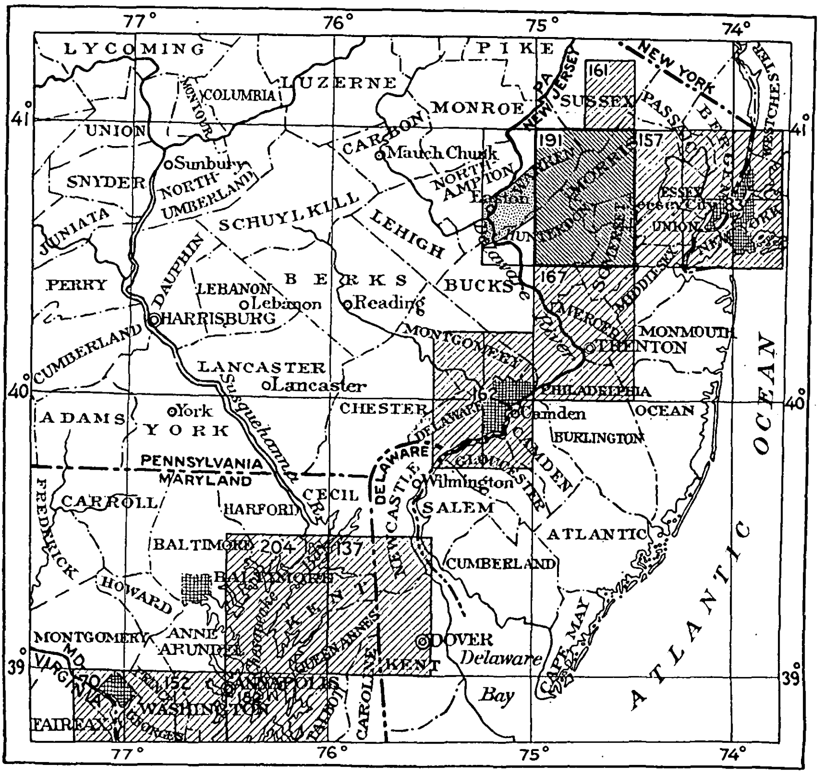


FIGURE 1.—Index map of New Jersey and adjacent States showing area described in this report (stippled) and areas described in folios of the Geologic Atlas of the United States (numbered): 70, Washington; 83, New York City; 137, Dover; 152, Patuxent; 157, Passaic; 161, Franklin Furnace; 162, Philadelphia; 167, Trenton; 182, Choptank; 191, Raritan; 204, Tolchester.

resources of the area. Consequently, in 1923 a few weeks were spent in revising the mapping of the area and in procuring data on the development of its mineral resources since the first visit. It was then realized that the map of the Pennsylvania side of the Easton quadrangle was so poor and that the culture had changed so much in the interval between the two field seasons that the geology could not be fitted to the topography shown. Consequently, it was decided to await a new map before publishing. A resurvey of the topography of the area was made in 1929, and during the summer of 1931 the area was again visited and the geology was adjusted to the topography and culture shown on the new map.

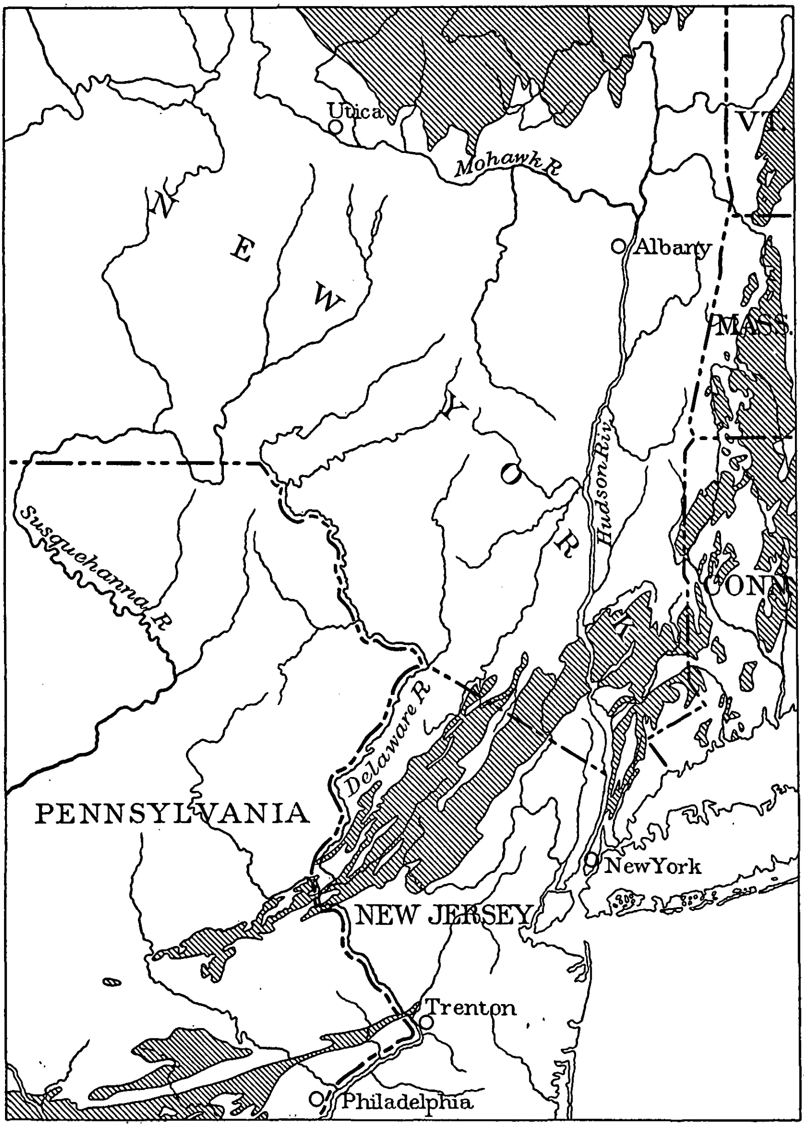


FIGURE 2.—Sketch map showing areas of pre-Cambrian crystalline rocks (shaded) in New Jersey and adjacent States.

In the interval of 25 years between the first and last visits to the area many of the old mines and quarries had been abandoned, their dumps had been removed, and it became impossible to discover their former sites. Nevertheless the manuscript has been left essentially as it was originally written, because it is recognized that the positions of many of the old openings may indicate the positions of potential future sources of material. Moreover, some of the iron mines, especially a few in the Franklin limestone, exhibited features that should be described as a matter of record.

TOPOGRAPHY

The general characteristics of the province of which the area studied is a part have been described so frequently that it is unnecessary to portray them again in detail. It is enough to state that the main portion of the area is occupied by the Highland ridges and their intervening valleys, which are the northeasterly extension of the better-defined Appalachian Mountains in the Southern States. The Highlands in most of New Jersey consist of several broad, flat-topped ridges rising about 600 feet above the lowlands on each side and separated by deep and generally narrow valleys. In this area, however, the ridges are lower and more rounded on top and are less well defined than farther northwest. In New Jersey they are known as Jenny Jump, Marble, Scotts, Pohatcong, and Musconetcong Mountains. The first three are well-characterized, individual ridges, from 300 to 700 feet above the bottoms of the valleys between them. Musconetcong Mountain, the southernmost of the ridges, is less individualized. On its north side it rises by a steep slope 500 feet above Musconetcong Valley, but on its south side it merges gradually into the high portions of the Piedmont Plateau, where they are underlain by Newark conglomerates and sandstones, and drops abruptly only between Spring Mills and Little York, where the underlying rocks are Newark shales. On the Pennsylvania side of the Delaware the ridges reappear, but not as distinct ridges comparable with those in New Jersey. They are rather linear assemblages of hills, with here and there well-marked peaks rising above the general level of the neighboring hills. As a rule the lines of hills are not characteristic enough to have received distinctive names, but the more prominent peaks have been named, and the lines of hills are usually designated by the same names. The only well-characterized ridge west of the river is the westward extension of Marble Mountain. This is Chestnut Hill, just north of Easton. It is separated from the height to the south by the valley of the Lehigh River and is bordered on the north by the Kittatinny Valley. Consequently it is an isolated ridge.

South of the Lehigh River, however, the assemblages of hills are separated by valleys for only a short distance from the Delaware River; beyond this they merge, forming an irregular plateau surface. Morgan Hill, Bougher Hill, and Rattlesnake Hill are the three most prominent peaks in the three assemblages of the highlands that represent the southwesterly extension of Scotts, Pohatcong, and Musconetcong Mountains, and the ill-defined ridges in which they are situated are usually designated by the same names. The name "Durham Hills" is applied in a more or less indefinite way to the hills in the vicinity of Durham, in the southwest corner of the area.

North of the Highland belt is the wide Kittatinny Valley, which represents the eastern part of the great Appalachian Valley of Virginia, Tennessee, Georgia, and Alabama, and south of the belt is the northwestern portion of the Piedmont Plateau, which in this area is chiefly a lowland of gently rounded hills separated by wide valleys, with a few ridges and isolated hills rising above the general surface. At the margin of the Highlands the general altitude of the plateau is about 400 feet, but near the Delaware River it is increased to 600 to 800 feet because the plateau is built up of Triassic sandstones and conglomerates that are resistant to erosion. From this margin the plateau slopes gently toward the southeast to an altitude of about 160 feet near Philadelphia and to sea level near New York.

The tops of the Highland ridges, some of which reach altitudes of more than 1,200 feet, are believed to be remnants of a dissected plateau surface sloping gently to the southeast; and the valleys between them, together with the Kittatinny Valley and a portion of the surface of the Piedmont Plateau, are thought to be the dissected remnants of a lower plain or perhaps of two plains whose average altitude differs by about 200 feet.

GENERAL GEOLOGY

The pre-Cambrian rocks, as has been stated, occupy belts extending from northeast to southwest through the area, forming in New Jersey the ridges known as Jenny Jump Mountain, Scotts Mountain and its southwest spur, Marble Mountain, Pohatcong Mountain, and Musconetcong Mountain and in Pennsylvania the extensions of these ridges west of the Delaware River.

Between the ridges are valleys underlain by Paleozoic quartzites, limestones, shales, and conglomerates ranging in age from Cambrian to Devonian. In some places the sides of the valleys are bounded by faults, and in others they are bordered by narrow belts of the Hardyston quartzite, of Lower Cambrian age, but some valleys are bordered on both sides by the quartzite, which crops out at the bases of the ridge slopes.

North of the belt of ridges is the wide Kittatinny Valley, underlain by Cambrian, Ordovician, and Silurian beds, and south of it the gently undulous plain that is a part of the Piedmont Plateau province. The plain within the area here considered is underlain for the most part by Newark conglomerates, sandstones, and shales, but here and there, close to the base of the southern ridge, are narrow strips of Paleozoic beds. The boundary between the gneisses of the Highlands and the rocks of the Piedmont Plateau is in general a fault plane, but at the west margin of the area the fault may lie between the Hardyston quartzite and the Newark beds.

HIGHLAND BELT

GENERAL FEATURES

The ridges of the Highland belt in this area are formed of gneisses, marbles, and intrusive igneous rocks that are generally gneissoid, besides pegmatites and a few dark dikes that intrude all the others.

The pre-Cambrian age of the gneisses and marble is shown by the fact that they are overlain by the Hardyston (Lower Cambrian) quartzite, which in some places contains water-worn pebbles of gneisses similar to the gneisses beneath it. The quartzite occurs not only between the gneisses and well-characterized Paleozoic beds, but in some places, as at the northwest end of Morgans Hill ridge and at Buttzville, N. J., it lies across gneiss layers, and everywhere it grades upward into the Paleozoic beds and is involved with them in the folding. In this area the quartzite is in contact with the marbles only at Lower Harmony, and there the relations are not clear, but in the Franklin Furnace quadrangle [1] the marble is demonstrably below the quartzite and is separated from it by an unconformity. Moreover, the marble is cut by pegmatite dikes and by masses of black rock like that here called Pochuck gabbro gneiss, whereas the quartzite is entirely free from intrusions of both rocks. Finally, in the quarries on the Delaware River, north of Easton, the marble is crushed, closely folded, and intensely sheared, whereas the quartzite is involved only in open folds and is sheared only near faults.

The gneisses are similar to those which occur farther east in the Highland belt and which have been described in the Passaic, Franklin Furnace, and Raritan folios [2] under the names "Pochuck gneiss," "Losee gneiss," and "Byram gneiss." They have been described in some detail in the Raritan folio, and it will be enough in this place simply to repeat in outline what has been said of them in that folio.

The marble is the Franklin limestone. It covers a wider area in the Delaware Water Gap and Easton quadrangles than it does in the Raritan quadrangle, but not as large an area as in the Franklin Furnace quadrangle. Near Easton associated with the limestone

[1] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), p. 3, 1908.

[2] U. S. Geol. Survey Geol. Atlas, Folios 157, 161, and 191.

are siliceous rocks that are unlike the quartzites and slaty rocks associated with the limestone in the Raritan area and, indeed, unlike any rocks seen elsewhere in the Highlands except on the northwest slope of Scotts Mountain, between Marble Mountain and Buttzville, N. J. Moreover, the limestone is more profoundly sheared than elsewhere in New Jersey. For these reasons the limestone and the rocks associated with it are discussed in some detail. As the limestone is the dominant formation it is described first, although the associated sedimentary schists, slaty rocks, and gneisses (here mapped as Pickering gneiss) are now generally believed to be older.

FRANKLIN LIMESTONE

GENERAL CHARACTER AND OCCURRENCE

The oldest rocks in the area comprise a series of marbles, quartzose sediments, and crystalline schists and gneisses which are cut by silicic and ferromagnesian dikes and by pegmatites and into which were intruded the great masses of igneous rocks that solidified into the gneisses here designated as the Pochuck gabbro gneiss, the Losee diorite gneiss, and the Byram granite gneiss. In most of the Highlands heretofore studied only the marbles have been separated from the gneisses and mapped as a distinct formation under the name "Franklin limestone," mainly because the associated siliceous rocks had been recognized over areas so small that their correlation was not attempted. Toward the west, however, the old schists, slaty rocks, and gneisses are more abundant, and in the Delaware Water Gap and Easton quadrangles they cover a comparatively large area and have been mapped under the name "Pickering gneiss." Their relations with the intrusive gneisses here are not any clearer than they are farther east, but in the Allentown quadrangle, in Pennsylvania, immediately west of the Easton quadrangle, where their relations to the gneisses are somewhat clearer, Miller[3] has found them to be older than the intrusive gneisses. Miller's conclusion is accepted for the old schists and gneisses in the present area, not only because it seems to be justified by the facts in the Allentown quadrangle but also because it explains better than any other supposition the conditions as they exist in New Jersey. The structural features of the old gneisses and schists in the Highlands have been explained as due to the intrusion of a liquid magma into preexisting series of rocks that had already had imposed upon them definite and pronounced structural characteristics, although only traces of such series had been detected. The discovery of large masses of old schists near the

[3] Miller, B. L., The geology of the graphitic deposits of Pennsylvania: Econ. Geology, vol. 7, pp. 772–775, 1912.

Delaware River and farther west furnishes a strong support for this view.

In the Franklin Furnace, Passaic, and Raritan folios[4] the Franklin limestone was described as consisting of crystalline white limestone and dolomite, a few beds of calcareous sandstones and slates, and layers of black schists that are unquestionably in part intrusive. These rocks are cut by pegmatite and by a few dark dikes. The limestone is the most prominent rock of the assemblage, the slates, sandstones, and schists being so scanty that they were not differentiated for mapping. In the Easton and Delaware Water Gap quadrangles the limestone continues to be the most prominent rock of the assemblage, but there are associated with it in some places, in addition to the slates and sandstones, also beds of quartzite and conglomerate. These beds, however, are so intimately involved with the limestone that they have not been separated from it. In addition to these undoubted sedimentary beds, there are, very closely associated with the limestone, layers of schists and gneisses that are very different from the characteristic gneisses of the Highlands, which have been called the Byram and Losee gneisses and, in part, Pochuck gneiss in the Passaic, Franklin Furnace, and Raritan folios. Most of them are much crushed, and many contain more or less mica. These are here grouped together and mapped separately as a distinct formation, under the name "Pickering gneiss." As now understood the Pickering gneiss includes all of these old sedimentary rocks except the white Franklin limestone.

COMPOSITION

The Franklin limestone consists of the well-known white marble that has its best development in the Franklin Furnace quadrangle. The rock, where not notably metamorphosed, is in general a coarse-grained white, gray, or bluish marble containing here and there a quartz grain, a particle of pyrite, small flakes of graphite, and a few crystals of a nearly white pyroxene. Near diorite and pegmatite dikes and near contacts with the intrusive Pochuck, Byram, and Losee gneisses, chondrodite, pyroxenes, garnet, and phlogopite are developed, and it contains prisms of tourmaline and crystals of sphene. Where the rock is sheared, tremolite, asbestos, and talc are commonly found, and serpentine and phlogopite are produced.

The Franklin limestone, where not greatly metamorphosed, is for the most part a nearly pure calcite. Nason,[5] as the result of a series of analyses, concluded that it is calcitic only where in contact

[4] U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), p. 3, 1908; Franklin Furnace folio (No. 161), pp. 3–4, 1908; Raritan folio (No. 191), pp. 6–7, 1914.

[5] Nason, F. L., The chemical composition of some of the white limestones of Sussex County, N. J.: Am. Geologist, vol. 13, pp. 154–164, 1894.

with pegmatite, but Kümmel[6] showed that where not near intrusives it varies in composition from an almost pure calcite to a typical dolomite; that, so far as has been determined, the influence of intrusives upon it is nil; and that the proportion of magnesium carbonate present in it varies from bed to bed. Magnesium carbonate constitutes about 40 percent of the rock in some beds, but usually it is less than 5 percent, and very few specimens contain more than 10 percent. The composition of samples collected from points in the Delaware Water Gap quadrangle is reported by Kümmel to be as quoted below:

Analyses of Franklin limestone from points in the Delaware Water Gap quadrangle

	1	2
SiO_2	0.80	1.08
$Al_2O_3+Fe_2O_3$	.64	.86
$CaCO_3$	94.93	94.41
$MgCO_3$	3.31	3.80

1. Average of samples from quarry 1 mile south of Buttzville.
2. Average of samples from quarry near road half a mile east of Hazen, on north side of Pophandusing Brook.

The records of the Edison Portland Cement Co. furnish an excellent means for determining the average composition of the limestone in the area north of the village of Oxford. Some years ago, when the great quarry of the Edison Co. was being opened, H. E. Kiefer, the chemist of the company, after a careful inspection of several thousand analyses made of drill cores, stated that they showed results within the following limits: SiO_2, 1 to 8 percent; Fe_2O_3 and Al_2O_3, 0.5 to 3 percent; $MgCO_3$, 2 to 20 percent; $CaCO_3$, 85 to 90 percent.

The analyses were made on samples that were free from silicates. Analyses of the dark-colored, more impure phases would unquestionably have shown a much higher percentage of silica, iron, and aluminum oxides, and in many samples higher percentages of magnesium carbonate.

DISTRIBUTION

In the quadrangles under discussion the Franklin limestone occurs in two fairly large areas and five small ones, the relations of which to the larger ones are not known. The larger ones are the Pequest and Chestnut Hill areas.

The Pequest area extends from Pequest Furnace westward to Hazen, a distance of about 2½ miles, with an average width of about

[6] Kümmel, H. B., The chemical composition of the white crystalline limestones of Sussex and Warren Counties (N. J.), with analyses by R. B. Crane: New Jersey Geol. Survey Ann. Rept. for 1905, pp. 175–191, 1906.

three-quarters of a mile. Here the predominant rock exposed is limestone, which at one place is so richly impregnated with sphalerite that attempts have been made to mine it as zinc ore. It ranges from a fine-grained white, gray, or bluish marble, containing a few quartz grains, pyrite crystals, graphite flakes, and crystals of white pyroxene, to a mottled ophicalcite, containing abundant chondrodite, pyroxene, garnet, phlogopite, tremolite, magnetite, and a few crystals of tourmaline and sphene. In some places serpentine and talc are also common. These components are especially abundant where the marble is cut by pegmatite or by dioritic intrusions. The only clastic rocks associated with the limestone in this area are a few thin beds of calcareous sandstone found in the quarries at its west end. Formerly several magnetite mines were operated in the area, but they have been abandoned and in 1924 the rock was being quarried for use as a flux and in the manufacture of cement.

The second large area, measuring about 4½ miles in length and from one-fourth to three-fourths of a mile in width, stretches along the south slopes of Chestnut Hill and Marble Mountain, crosses Bushkill Creek, northwest of Easton, and extends southwestward to the edge of the Easton quadrangle. The limestone is brought to the surface by a fault or an anticline a little farther west, where it is exposed in an area about three-fourths of a mile long and one-fourth of a mile wide. Three extensions to the northeast cross the Delaware River and furnish exposures in the midst of gneisses and schists in the river bank at the southwest end of Marble Mountain.

The smaller areas are at Lower Harmony, at the east end of Marble Mountain, and two small patches in the hills east of Roxburg.

In all these areas the rock has been quarried or prospected, and it is only by the aid of these openings that some of the exposures can be studied.

Aside from the great Edison quarry, near Pequest, the principal quarries[7] in the Franklin limestone are those in the belt of metamorphosed rock on the south side of Chestnut Hill, where the varieties containing talc and serpentine have been exploited as mineral pulp and as material for stucco and terrazzo.

PICKERING GNEISS[8]

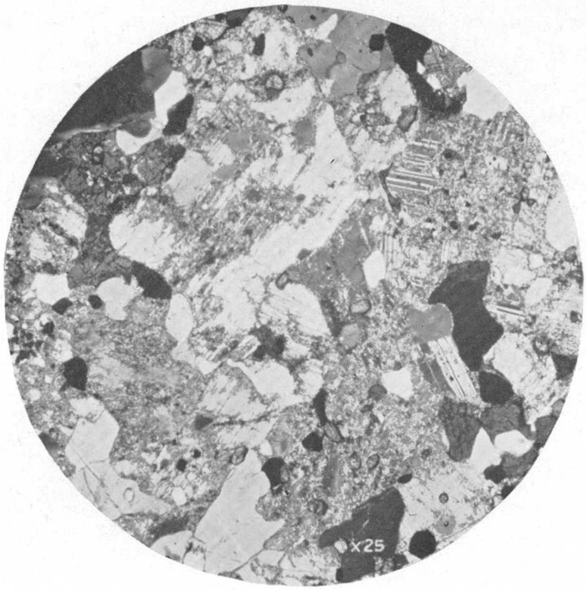
DISTRIBUTION

The old crystalline schists, gneisses, and slaty rocks associated with the Franklin limestone in the Delaware Water Gap and Easton

[7] Most of these quarries have been abandoned, and their sites are lost.

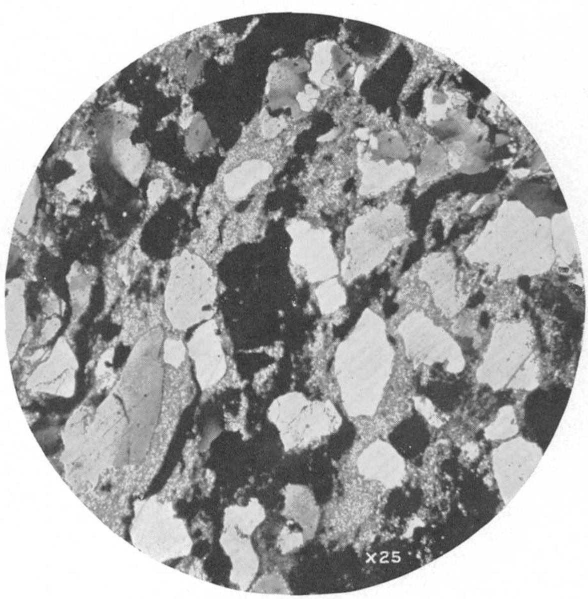
[8] Dr. F. Bascom has furnished the following note:

"When the rocks of the Phoenixville quadrangle were mapped the writer separated the graphitic gneisses from the nongraphitic gneisses and proposed to apply to them the



A. PHOTOMICROGRAPH OF GNEISS FROM BANK OF DELAWARE RIVER ABOUT 2 MILES NORTH OF EASTON, PA.

Cracked and partly sericitized plagioclase, cracked and strained quartz, irregular grains of magnetite, and small round grains of sphene. A little hornblende at center and in lower right quadrant. Polarized light.



B. PHOTOMICROGRAPH OF QUARTZ-SERICITE SCHIST FROM FULMER MINE, WEST END OF MARBLE MOUNTAIN.

The black is magnetite and hematite; the groundmass is a very fine aggregate of sericitic material; the white grains are cracked and strained quartz. Polarized light.

quadrangles are well exposed at the southwest end of Chestnut Hill, in the channel of the Delaware River at Easton, and on its east bank above Phillipsburg and near Roxburg. They also form the axis of Chestnut Hill and of Marble Mountain and occur over an area extending northeastward as a strip about a mile wide from Marble Mountain to Buttzville. Rocks of a more or less similar type also form the main portion of Morgan Hill, south of Easton, and are scattered here and there through the areas in which the Losee, Byram, and Pochuck intrusive gneisses are mapped as the predominating rocks.

VARIETIES

The variation in these lighter-colored old layered schists and gneisses is so great that it is impracticable to attempt to describe each type. Many of them are mica schists; others are rather dense pink rocks that apparently are crushed silicic igneous rocks; and others are feldspathic schists characterized by the presence of much epidote and in some places of notable quantities of tourmaline. They show abundant evidence of crushing. Their quartzes are strained and granulated at their borders, their feldspars are fractured and much altered (pl. 1, *A*), and there are present in them more or less epidote, tourmaline, and sphene and usually comparatively large quantities of a white mica that apparently is secondary. They are cut by pegmatites and have associated with them layers of rock closely resembling the Byram and Losee gneisses, which are schistose but show no evidence of crushing except along faults. They occur commonly in distinct layers with parallel strikes and dips. The pegmatites associated with them and the rocks that are similar to the Byram and Losee gneisses also occur in layers. In their field relations they suggest a sedimentary series that has been intruded along their bedding by pegmatites and other magmas. In every respect these layered rocks appear to be older than the Pochuck, Byram, and Losee intrusive gneisses and to have undergone a great deal more metamorphism.

In addition to the lighter-colored schists and gneisses among these older rocks, there are also numerous layers of dark schists that for

geographic name 'Pickering gneiss,' restricting the name 'Baltimore gneiss' to the nongraphitic rocks, and the name and definition of Pickering gneiss were published in an article by B. L. Miller (Econ. Geology, vol. 7, p. 67, 1912). Further work on the pre-Cambrian gneisses of southeastern Pennsylvania and Delaware led the writer to consider the graphitic gneiss associated with recognized Baltimore gneiss as essentially a facies of that formation and not a distinct formation. In the Coatesville-West Chester folio (No. 223), published in 1932, the graphitic gneiss was included in the Baltimore gneiss and the name 'Pickering gneiss' was discarded. Later, however, in deference to a decision by the committee on geologic names of the United States Geological Survey, the name 'Pickering gneiss' was restored to use for the pre-Cambrian sedimentary rocks associated with the Franklin limestone."

convenience have been mapped with the Pochuck gabbro gneiss. Hornblende schists, amphibolites, biotite schists, and "green schists" are common, and others composed of bright-green pyroxene, green and brown hornblende, and plagioclase are frequently encountered. All these rocks are identical with some that were included with the Pochuck gneiss in the Raritan, Franklin Furnace, and Passaic folios. In those folios the Pochuck gneiss is considered as comprising certain rocks that are basic differentiates of the Byram and Losee gneisses and others that probably represent an old series of sedimentary and igneous schists into which the Byram and Losee magmas were intruded. In the areas covered by those folios it seemed impossible to separate the two kinds. In the Delaware Water Gap and Easton quadrangles the two kinds are intermingled in Pohatcong Mountain and in the hills west of Raubsville and also in a narrow strip south of Buttzville. In these areas there has been no attempt to separate the two kinds, and the areas covered by them are mapped as Pochuck gabbro gneiss, with the explanation on the map that as mapped some gneiss and schist of sedimentary origin that properly belong to the Pickering gneiss are included. Elsewhere in these quadrangles the dark schists are subordinate to the lighter-colored schists and gneisses and are mapped with them as Pickering gneiss.

Light-colored schists and gneisses corresponding to those described above are known to occur also in the Raritan and Passaic quadrangles, but they cover areas so small that they have not been separately mapped. The Raritan folio[9] describes as being present with the Franklin limestone certain light-gray graphitic quartzites, containing small amounts of tremolite, colorless pyroxene, muscovite, sphene, biotite, serpentine, and calcite that were regarded as calcareous sandstones which had been subjected to the same metamorphosing influences as the limestone, and certain slaty rocks that were regarded as sheared volcanics. The latter are exhibited best at Pottersville Falls, on the Black River, where they are exposed for a few hundred yards below the falls as a series of finely banded and slightly schistose, dense light-gray, dark-gray, or purple rocks, composed of lenses and round masses of quartz and epidote in a fine granular quartz aggregate crossed by streaks of tiny brown grains. The components are arranged in sinuous light and dark bands, producing an appearance resembling flow banding. These rocks were believed to be ancient rhyolitic lavas.

The Raritan folio also described a few exposures of graphitic quartz-mica schist. In the Raritan quadrangle this schist is found only in small masses in the midst of gneisses, generally interstratified with thin seams of hornblende schist, but at some other places in the

[9] Bayley, W. S., U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 7, 1914.

Highlands it is associated with the Franklin limestone. The schist occurs ordinarily in thin layers that extend for short distances along the strike. Because of its association with the limestone, its occurrence in small lenticular masses, and its composition, the schist is inferred to be a metamorphosed sedimentary rock.

Other graphitic schists and certain graphitic gneisses occurring in the Raritan and Passaic quadrangles are garnetiferous. They include coarse- and fine-grained aggregates of quartz, feldspar, mica, garnet, magnetite, pyrite, and graphite with a very strongly schistose structure, especially where richly micaceous. Some of these rocks are unquestionably sheared pegmatite dikes, but others may be metamorphosed sedimentary rocks.

Another group of rocks in the Raritan quadrangle that were regarded as possibly representing sediments are characterized by containing large amounts of epidote. One area of these rocks is just northwest of Pequest Furnace, where there are a few outcrops of well-banded fine-grained gneisses containing much epidote and others that are fairly fine grained mica schists containing nodules of feldspar. Some of them are apparently permeated with pegmatitic material. Their general aspect is that of thin-bedded sedimentary schists, but study of their thin sections reveals no evidence either for or against this view. They are similar in general character to some forms of the Byram gneiss but are much more profoundly altered. Epidote and kaolin were made from feldspar, garnets were developed, and notable quantities of tourmaline were produced. As the Byram gneiss rarely contains epidote, garnet, or tourmaline and nowhere in large quantities, it was thought that these banded schists are much older than the Byram and that they probably represent siliceous sediments that have been so thoroughly permeated with the Byram gneiss magma that they have assumed the general character of that gneiss.

Another epidotic rock, occurring at several points northwest and southeast of Gladstone, is a light-gray coarse crystalline aggregate of nearly white epidote, flakes of graphite, a few quartz grains, and here and there a flake of biotite. The rock has been explored for graphite. On some of the dumps of the pits are fragments of chondroditic limestone. It is understood that this epidotic rock so closely associated with the Franklin limestone is a part of the schists and gneisses here called Pickering gneiss.

All these rocks are intimately associated with the Franklin limestone and have heretofore been regarded as parts of that formation that have been profoundly metamorphosed or as metamorphosed phases of sedimentary beds and igneous intrusions interleaved with the limestone, though no certain evidence of this relation to the limestone was seen.

In the Easton and Delaware Water Gap quadrangles the close association of similar rocks with the limestones in the Delaware River and on Marble Mountain seems to demand that all the rocks so associated should be regarded as parts of the same formation, and the observations of Miller [10] in the Allentown quadrangle, which is west of the Easton quadrangle, reinforce this view. As a result of his studies in the graphite deposits of Pennsylvania, Miller [11] concludes that the graphitic gneisses, which are similar to the graphitic gneisses in New Jersey, are calcareous in many places and that they grade into a limestone that is correlated with the Franklin limestone and into nongraphitic gneisses.

The graphitic gneisses are described by Miller as being composed primarily of feldspar, quartz, biotite, hornblende, calcite, and graphite, with pyrite, pyrrhotite, magnetite, epidote, sillimanite, garnet, and other alteration products of the primary minerals as accessories. They are, however, extremely variable in composition. Some layers are practically quartz schists, others contain biotite but no graphite, others contain both biotite and graphite, and still others contain so much calcite that they might fairly be called calcareous gneisses. In many places it is impossible to draw a sharp line between the Franklin limestone and the calcareous graphitic gneisses.

The two formations were formed originally as contemporaneous sediments that varied in different places. In some localities fairly pure limestone was being deposited, while in adjacent regions were accumulating calcareous muds or siliceous muds in which there was little or no calcareous material. When these sediments were later metamorphosed, the beds composed mainly of calcareous matter formed the rocks called the Franklin limestone; the calcareous muds gave rise to the calcareous graphitic gneisses; the muds with little calcareous matter formed the bulk of the Pickering gneiss; and the more siliceous sediments formed the quartz schists. If the limestone and the [Pickering] gneiss are conformable, as believed, with the limestone intercalated within the gneiss, the logical conclusion follows—that the two are of contemporaneous origin and represent merely different lithologic phases of the same series of sediments.[12]

Rocks of the same kind in the New Jersey Highlands are as a rule not so closely associated with the limestone as they are in Pennsylvania, but they are so like the schists and gneisses described by Miller that they can fairly be correlated with them. The most com-

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[10] Miller, B. L., personal communication.

[11] Miller, B. L., The geology of the graphitic deposits of Pennsylvania: Econ. Geology, vol. 7, pp. 762–775, 1912. See also Bascom, F., and Stose, G. W., Geology and mineral resources of the Honeybrook and Phoenixville quadrangles, Pa.: U. S. Geol. Survey Bull. 891, pp. 19–23, 1938.

[12] Idem, p. 774.

plete similarity is exhibited by the graphite-mica schists in the two areas. They are not as common in the New Jersey Highlands as they are in Pennsylvania, but they occur at widely separated places. One of these occurrences is at the Bloomingdale mine, 1½ miles west of Pompton, in the Passaic quadrangle,[13] where a pegmatite and the biotite gneiss in contact with it are impregnated with graphite. Again, at Tuxedo Park, which is in the Ramapo quadrangle just across the State line in New York, Stewart[14] found a graphitic pegmatite cutting Franklin limestone and associated schists in a belt a mile long and 20 to 300 feet wide. At the extreme northeast end of the belt is a layer of graphitic quartz schist that extends through the center of the limestone. Its exposed length is 900 feet, and its width is 20 to 60 feet.

No limestone has been observed in the southwestern part of the Tuxedo Park area, where the series is represented by the graphitic schist alone. This rock occupies several long, narrow belts from several feet to 100 feet wide and is entirely surrounded by pegmatite. It is so rich in graphite that proposals have been made to mine it. Similar rocks have been exposed in pits west and southwest of High Bridge, in the Raritan quadrangle. Other areas of graphitic gneiss are known in the Highlands, but they are small and most of them are probably squeezed pegmatites.

In Pennsylvania the representatives of sedimentary rocks associated with the Franklin limestone are now chiefly gneisses and schists. Quartzites are rare. In New Jersey, however, sandstones, quartzites, and conglomerates occur in the Franklin Furnace and Easton quadrangles in such relations that they are believed to be a part of the series of sediments to which the name "Pickering gneiss" is here applied. In 1908 Spencer[15] mentioned the occurrence of thin beds of sandstone in the limestone, and in his description of the Andover mine[16] he stated that layers of siliceous breccia and indurated carbonaceous shale, about 100 feet thick, are associated with the ores.

The presence of coarsely crystalline white limestone in the vicinity suggests that the siliceous beds found at the mine are part of the series of sedimentary beds belonging with the white limestone of the Franklin region.

Again, he describes the hematite at the Simpson and Cedar Hill mines, near McAfee, as occurring in irregular layers interbedded

[13] U. S. Geol. Surv. Geol. Atlas, Passaic folio (No. 157), p. 25, 1908.
[14] Stewart, A. C., Note on the occurrence of graphite schist in Tuxedo Park, N. Y.: Econ. Geology, vol. 3, p. 535, 1908.
[15] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), p. 3, 1908.
[16] Idem, p. 20.

with sandstone and shaly material that dip southeast and are overlain by white limestone.[17] At the Cedar Hill mine

a stratum of hard green rock about 50 feet thick stands in a nearly vertical position between walls of white limestone. It contains abundant pebblelike but more or less angular fragments of quartz up to about one-fourth of an inch in diameter set in a matrix of chlorite, and throughout the mass, as seen near the surface, there is considerable red hematite in an amorphous or noncrystalline condition.

Similar quartzites and conglomerates occur also at the Fulmer mine, on Marble Mountain. (See p. 26 and pl. 1, *B*.)

From the foregoing it is evident that there is in the Highlands a series of schists and gneisses which are different from the predominating gneisses of the district and which at many places are evidently closely associated with the Franklin limestone and at some places apparently grade into the limestone. They are regarded as sedimentary. Their relations to the Pochuck, Byram, and Losee gneisses are not clear, but as Pochuck, Byram, and Losee are believed to be intrusive in the limestone it is inferred that they are also intrusive in the sedimentary gneisses and schists associated with the limestone. The sedimentary schists, slaty rocks, and gneisses are here included under the name "Pickering gneiss;" and the Pochuck gneiss—of which they have heretofore been treated as a part—is restricted to the black gneisses of igneous origin which are intrusive in the Franklin limestone and the sedimentary gneisses and schists. The relations of these older gneisses to the limestone have not been determined at any place in New Jersey, but Miller [18] finds that at the few localities in the Allentown quadrangle, Pa., where the Franklin limestone has been observed in contact with the sedimentary gneiss, the limestone overlies the gneiss, and no other type of pre-Cambrian sediment has been observed above it. Miller also finds that the limestone is more commonly in contact with the Lower Cambrian Hardyston quartzite than the rest of the sedimentary series (Pickering gneiss). For these reasons he believes that the limestone is younger than the gneiss.

It appears, therefore, that the Franklin limestone is only one member of a series of pre-Cambrian rocks including, in addition to the limestone, also quartzites, conglomerates, slates, banded gneisses, and layered micaceous schists of sedimentary origin and that the limestone lies above and is younger than the other sediments. Many of these rocks have been so thoroughly metamorphosed, however, that their fragmental character is greatly obscured; but there can be little doubt that they are sedimentary rocks older than the intrusive

[17] Spencer, A. C., op. cit., p. 23.

[18] Miller, B. L., personal communication. See also Pennsylvania Geol. Survey, 4th ser., Topog. and Geol. Atlas, No. 206, Allentown quadrangle, 195 pp., 11 pls., 2 figs., 4 maps, 1925.

gneisses which surround them and that they represent a continuous deposition in pre-Cambrian seas.

Farther southwest, in Maryland and Pennsylvania, Knopf and Jonas [19] suggest the correlation of the schists of the Reading and Durham Hills and their extensions to the northwest with the Baltimore gneiss. Miller [20] thinks that there is a gradation between the Franklin limestone and associated schists and that they represent a single period of sedimentation.

PRINCIPAL AREAS OF FRANKLIN LIMESTONE AND PICKERING GNEISS

GENERAL DISTRIBUTION

The areas in which the Franklin limestone is the predominant rock assemblage are deserving of a more detailed description, because in those areas the relations of the limestone and the siliceous rocks (Pickering gneiss) can be seen and their close association may be appreciated. It would seem unnecessary to describe the areas in which only the siliceous rocks are exposed, for these areas exhibit only a succession of interlayered schists and gneisses, with here and there interleaved magnetite lenses, that are not in any essential respects different from corresponding series of schistose rocks found at many other places in the Appalachian Mountains and the Piedmont Plateau. Some of the schists will be described, incidentally, in connection with the description of the limestone, but only in enough detail to give an idea of their general character where closely associated with the limestone.

The limestone has been found at several places east of Roxburg, N. J., in the midst of an area of siliceous schists about 1 mile wide that extends from the Delaware River northeastward to the Pequest River, a distance of 12 miles.

Another area is at Lower Harmony, N. J., at the northeast end of Marble Mountain, where the limestone has been opened by several quarries, which were once an important source of building stone. This area is on the east side of the strip of schists referred to in the preceding paragraph.

At the north end of this same belt of schists is the Pequest area, so called because it contained mines that furnished ore to the old Pequest furnace. Near Oxford Church the belt forks, and between its two prongs is a lenticular area underlain by the limestone. About

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[19] Knopf, E. B., and Jonas, A. L., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, pp. 68–70, 1929.

[20] Miller, B. L., Graphite deposits of Pennsylvania: Pennsylvania Topog. and Geol. Survey Report 6, pp. 81–82, 1912; Geology of the graphite deposits of Pennsylvania: Econ. Geology, vol. 7, No. 8, pp. 772–774, 1912; Limestones of Pennsylvania: Pennsylvania Topog. and Geol. Survey Bull. M 7, pp. 61–62, 1925.

half of the area is within the Delaware Water Gap quadrangle, the other half lying in the adjacent Raritan quadrangle, to the east. The western half is about $2\frac{1}{4}$ miles long and about 1 mile broad at its widest part, which is at the east border of the quadrangle. The only exposures of the limestone are at the quarries on the road running northeast from Hazen, but the large opening of the Edison quarry, in about the center of the area, gives an excellent view of the underlying rock. The most important area commercially of the Franklin limestone lies along the southeast side of Chestnut Hill in Pennsylvania and extends in three narrow tongues northeastward across the Delaware River into New Jersey, one in each side of the southwest end of Marble Mountain and the third between these two, represented by a small exposure surrounded by schists. An isolated small patch of limestone at the southwest end of Chestnut Hill is treated as a part of the same area. The Chestnut Hill area is known principally from the large number of quarries that have been opened in it, though natural exposures occur in the banks of the Delaware River.

LOWER HARMONY AND ROXBURG AREAS

At Lower Harmony the limestone is exposed only in a quarry opening, where it is seen to be cut by a few dikes of pegmatite. Some beds have a light-green hornblende, a little biotite, and a little tourmaline. Others contain a few lenses of coarse feldspar mixed with dark-green and light-green hornblende and some tourmaline. Most of the rock, however, is a granular white limestone composed only of carbonates. There are no siliceous schists intimately associated with the limestone, but boulders of Hardyston quartzite occur at the bottom of the slope to the east, indicating the presence of a bed of this rock separating the white marble from the overlying blue Kittatinny limestone, of Upper Cambrian and Lower Ordovician age.

Near Roxburg the only limestone seen was taken from the dumps of old pits. It is a coarse-grained bluish-gray marble containing a great deal of talc along shearing planes. The marble between the shearing planes contains in addition to the carbonates only a few flakes of reddish-brown biotite, sparse crystals of white pyroxene partly changed to a mixture of calcite and very light-green amphibole, and a few particles of graphite.

Between the pits and the bottom of the western slope are outcrops of schistose rocks that are quite different from the prevalent gneisses of the Highlands but are so much altered that little can be learned of their original character. Some of them exhibit an arrangement of decomposition products that suggests a diabasic texture or the texture of some of the darker dike rocks. They now consist of sericite, chlorite, calcite, epidote, quartz grains, lath-shaped crystals of saussuritized feldspar, little nests of some mineral traversed by actinolite spicules, and scattered almost uniformly through this aggregate skeleton crystals of titaniferous magnetite partly changed to a mass of gray material resembling leucoxene and little aggregates of this material pseudomorphous after crystals of the magnetite and also a few small flakes of biotite. Under the microscope the rocks are seen to be crossed by small seams of crush breccia.

Most of the siliceous rocks in the neighborhood of the limestone are badly crushed and greatly changed in mineral composition. Exposures are rare except on the steep slope overlooking the valley of the Delaware River. Thus the knob southwest of Oxford Church is described in the field notes as being composed in places of sheared arkosic conglomerate with mashed pebbles of pink feldspar. The rock is gently distorted but in general it dips into the hill. At a point just north of the Roseberry mine it is associated with a jasper-like slate which is much more contorted than the conglomerate. A few fragments were found that showed bright-red jasper layers alternating with hematite layers, like the jaspilite of the iron-ore ranges in Michigan. At one place on the northwest slope of the ridge, about three-quarters of a mile from its southwest end, the slate appears to wrap around a sheet of very feldspathic gneiss 2 feet wide as if it had been squeezed against it and overturned. As this steep slope is an escarpment along the fault that separates the pre-Cambrian rocks from the Kittatinny limestone to the northwest, it is probable that the contortion is due to the faulting, and possibly the supposed conglomerates may be sheared gneisses. In the field the slate was thought to be a phase of the Hardyston quartzite, but the examination of its thin sections indicates that it is crushed, sheared, and saturated with tourmaline and therefore is probably pre-Cambrian and belongs to the series of sediments here designated Pickering gneiss. The rock is a mass of small fragments of quartz in a cement of chlorite, sericite, a little calcite, and hematite dust. Through this cement are scattered crystals and fragments of a yellowish-brown tourmaline, many small crystals of rutile, and a few fragments of a pink mineral taken to be andalusite. The average size of the tourmaline particles is 0.12 by 0.12 millimeters, though many measure 0.3 by 0.24 millimeters, and the average size of the rutile crystals is 0.03 by 0.06 millimeters. A few rutiles are 0.22 millimeters long by 0.06 millimeters thick. The rock is evidently a fragmental rock that is much more altered than any specimen of the Hardyston quartzite that has been seen and therefore is probably much older than the Hardyston. It resembles so closely some of the fragmental rocks in the Delaware River (p. 26) that it is correlated with them. The existence in it of abundant tourmaline suggests also its close relationship with some of the schists on the road along the east side of the river.

PEQUEST AREA

In the Pequest area the marble is usually blue or gray and slightly schistose. Where not close to intrusive masses it consists of calcite or dolomite with chondrodite, a little graphite, phlogopite, pyroxene, and serpentine. Where cut by basic intrusive rock, as at the Raub mine, or by pegmatite, as at the Ahles mine, its composition is much more complex. Chondrodite, phlogopite, pyroxene, and magnetite become very abundant and in some places much pyrite is developed, and the marble changes to a uniformly dark-gray fine-grained rock, or to a mottled rock with a light-colored groundmass of calcite, speckled with small yellow or black spots. Of these contact metamorphic minerals chondrodite is most common. It is only rarely fresh. Most particles are altered to a mixture of serpentine and magnetite, with the iron oxide forming zones around the borders of the grains and tiny veins traversing its mass. The phlogopite is in golden-yellow and brown flakes. It is present in nearly all specimens but usually in small quantity only. Where local shearing has taken place, however, the mica may occur in sufficiently large quantity to constitute a well-defined layer in the limestone.

At the old zinc mine a few rods southwest of the Raub iron mine [21] the limestone is interbanded with an epidotized dark rock and with seams of coarse hornblende. Many of the dark bands are but an inch or two in width, but one is several feet wide and resembles a dike. In thin section the material of the dark bands is observed to be composed principally of a mottled mass of green hornblende and epidote, a few flakes of biotite, small crystals of apatite, and tiny veins of calcite. Other sections show in addition sphene, quartz, and a little microcline and other feldspars. The limestone in the vicinity is impregnated with a transparent yellow sphalerite that is scattered uniformly through the rock and is cut by very irregular veins of a dark-brown variety of the same material. Here and there are tiny veins of galena, but the lead sulphide is not common.

On the mine dump in 1905 and in the Edison quarry, which in 1923 had completely obliterated the mine, in the limestone quarry nearest Hazen, and at other places was seen a large amount of a mottled white and dark-blue rock composed of flat, long, parallel lenses of dark-blue calcite in a ground mass of white calcite. In some occurrences the dark and light portions are layers that are apparently the result of sedimentation. In others the dark portions are distinct lenses in the white portion, composing about a third of the rock's mass. In the hand specimen the limestone might easily be mistaken

[21] The sites of most of the mines referred to in this description of the Pequest area cannot be found, as the dumps have been carted away or have been used for filling the abandoned shafts.

for a gray gneiss. There is no essential difference between the dark and white limestone except that the former contains innumerable specks of a dark pigment. The structure is probably the result of shearing.

Other gneisslike rocks occur on the footwall of the Ahles mine ore body, which dips 80° S. One phase is a silicified limestone that is irregularly mottled in light and dark gray. Another is a rock with a distinctly gneissoid structure which results from the presence of numerous parallel streaks of black silicate minerals in a light-gray ground mass. In the hand specimen the latter rocks are identical in appearance with some of the darker varieties of the Byram granite gneiss.

The mottled rocks are aggregates of colorless pyroxene, serpentinized chondrodite, biotite, and calcite. Tiny veins of serpentine and of magnetite cut through the chondrodite and calcite and occupy the cleavage cracks of the pyroxene. A part of the calcite is in the form of grains enclosed in the pyroxene. In the phases with the gneisslike structure the calcite is reduced to a few nests and some small veins. The rock is an aggregate of green hornblende, green augite, and various feldspars, with the amphiboloids forming the streaks and the feldspars the ground mass. The relation of this rock to the mottled rock is not known, as both were seen only on the dump from the slope of the Ahles mine, but both are described as forming the footwall of the ore vein. The mottled rock is clearly a metamorphosed marble; the gneissoid variety may be a more highly metamorphosed rock of the same general character, or it may represent a narrow layer of Byram granite gneiss in the limestone.

Near some of the ore deposits the limestone has also other unusual features, which are best noticed on the weathered surface of fragments taken from the dumps of the Queen and Little mines. The limestone near the ore is very dark bluish gray and is crossed by series of tiny black veins, which on weathered surfaces project as ridges. In thin sections specimens are seen to consist of a mass of serpentine and calcite, with here and there a large crystal of magnetite. The serpentine in places occupies circular areas which suggest that it originated from chondrodite, but in general it is distributed through the slide in large irregular areas that include areas of calcite. Thousands of tiny veins of magnetite cross the serpentine in two or three directions as if occupying shrinkage cracks in the serpentine mass; most of them, however, are approximately parallel. Unfortunately it is not possible to study these rocks in place, and any opinion of their significance is of doubtful value. It appears most probable, however, that their peculiar character is due to the same processes that gave rise to the ore—that is, that the iron which they contain was introduced in large part at the same time that the ore bodies were deposited and by the same agencies.

The walls of the great Edison quarry afforded, in 1925, the best exhibition of the various phases of the limestone that was to be found anywhere. The rock then seen was much contorted but not as badly sheared as in the quarries on the Delaware River, and consequently not as many new minerals had been developed in it, though many different varieties of marble have been produced. A large part of the marble then visible was a fine-grained, sugary white rock interbanded with a coarse-grained gray phase that was in many places charged with pyrite. Other portions were very coarse grained gray varieties that had recrystallized without deformation, as gray lines marking the darker laminae passed through contiguous crystals without distortion. In some places, however, there were narrow shear zones in which the rock was schistose and very fine grained. Graphite was abundant in the white layers, and pyrite and pyrrhotite in the darker layers. In many places the lighter-colored limestone, which was the predominating variety, contained lenses of the darker phases, other lenses of a mixture of serpentine and black quartz, and others of dark siliceous aggregates that apparently represented fragments that were sheared off of dikes during the process of folding.

Here and there on the quarry walls were streaks of dark siliceous rocks that appeared to be intrusions, but their relations with the limestone were not clear. There were no very sharp contacts between the two rocks, and the siliceous ones wedged out gradually. One such siliceous mass in the northwest corner of the quarry was fairly well defined in the bottom of the pit, but it seemed to terminate above before it reached the surface. Another such mass was exposed in the south wall toward its west end. It was similar to that at the northwest corner of the quarry, and its relations to the limestone were equally obscure. Near it, however, the marble was very coarse grained and was richly charged with purple fluorite and contained many grains of pyrrhotite. That these masses were probably dikes is indicated by their mineral composition. The rock in the south wall of the quarry was composed of dark-brown hornblende, pale epidote, possibly clinozoisite, plagioclase between oligoclase and andesine, and considerable unstriated albite. Scattered through this aggregate were many grains of titaniferous iron oxide surrounded by narrow zones of leucoxene. The structure was aplitic, and all the components but the iron oxide were approximately equant and of about the same size (0.1 to 0.2 millimeter). The rock in the northwest corner differed from that just described in that it contained no epidote and its iron oxide showed no evidence of containing titanium. Moreover, it was crushed, and the crush debris contained much calcite. Its hornblende was paler than that in the southern mass, and the grain a little coarser (0.12 to 0.20 millimeter). Its feldspar was mainly, if not entirely, andesine or labradorite. Its texture, where not distorted by crushing, was aplitic. Both rocks were probably dioritic aplites.

The lenslike inclusions that were thought to be fragments pinched from dikes were of varied character. Only a few of them bore even a remote resemblance to the dike material just described. That which most nearly resembled it was a grayish-green rock that was fine grained except around its borders, where there was a rim of coarse-grained tremolite. In thin section it shows granular tremolite and colorless epidote, a great deal of calcite, and large areas of a shattered plagioclase, in the cracks of which are little veins of calcite and epidote, and through the body of which are many fibers of actinolite, usually radiating from inclusions of epidote. Where the feldspar was badly crushed it was almost entirely replaced by epidote and calcite, and where the epidote was crushed calcite served as a cement between the fragments. It is probable that the original rock was like that of the dikes. If so, it had been metamorphosed, partly through the assimilation of calcite from the marble, and had later been crushed. Most of the calcite now present in it is apparently an infiltration.

Another lens was a very fine grained, slightly schistose reddish-brown micaceous mass, surrounded by a thin rim of dark-gray tremolite and a much wider rim of coarse calcite and tremolite. It was composed mainly of dark reddish-brown biotite, colorless epidote, and feldspars. In its thin sections sphene is abundant in large grains, and a small quantity of bright-green hornblende occurs around the edges of some of the epidote grains. Between the feldspars there is also present a little calcite in nests and veins and a dust of magnetite in small scattered areas as if marking the position of some mineral that has been destroyed. The feldspars are plagioclases and microperthites, and where they are crushed they have been changed to a fine-grained micaceous aggregate. The biotite grains measure about 0.15 by 0.5 millimeter, and the feldspar and epidote grains about 0.2 by 0.3 millimeter.

A third type of inclusion was represented by a dense black elliptical mass measuring about 14 by 11 inches in vertical section. Its thin sections show an interlocking matrix of unstriated feldspar in which are plates and radiating bunches of fibers of an ash-gray micaceous mineral that is probably muscovite colored by graphite, tufts of needles of the same substance, large irregular grains of brown sphene and of reddish-brown rutile, and streaks of granular greenish-yellow epidote. Comparatively large irregular grains of graphite are enclosed between the plates of the mica, and here and there is a crystal of apatite.

The last two rocks are quite different from the dioritic aplites that occurred as dikes, but nevertheless, because of the comparatively large amount of feldspar in each they are believed to be igneous rocks that have been greatly changed in character, not only by dynamic metamorphism, but also as the result of the assimilation of calcite from the marble which they intruded.

CHESTNUT HILL AREA

One of the most interesting occurrences of the Franklin limestone anywhere in the Highlands is that which forms the belt on the south slope of Chestnut Hill and the southwest slope of Marble Mountain. The limestone and the associated schists (Pickering) are well exposed on the road along the east bank of the Delaware River and in the quarries on its west bank, about 1½ miles above the Easton-Phillipsburg bridge. On the west side of the river, on the southeast slope of Chestnut Hill, is a large quarry in the limestone, operated by C. K. Williams & Co., and several openings in the same rock that are now abandoned. South of the quarry is an exposure of pegmatite, and north of it a cliff of schists affording a complete section through the hill at its northeast end. On the east side of the river another quarry, worked by the Rock Products Co., in 1923, is at the mouth of the little valley separating Marble Mountain, on the south, from the northeast extension of Chestnut Hill, on the north, and there is an abandoned quarry in a wedge of limestone in the midst of Pickering gneisses and schists, about half a mile farther south.

In the channel of the river about opposite the Williams quarry is a series of layered gray, green, or red rocks, and with them a few layers of black rock resembling a hornblende schist. At the southwest end of Marble Mountain are other rocks which are somewhat different from those in the river channel. At the base of the hill they are not marked by characteristics that distinguish them sharply from those in the river, but on the hill near the opening of the old Fulmer iron mine there are abundant exposures of light-gray talcose schists, of somewhat similar rocks containing reddish nodules that resemble decomposed granite pebbles, of purplish-black, very fine grained homogeneous slate that is completely puckered, of quartzites, and of quartzose conglomerates. Associated with the quartzites and quartzose conglomerates are strongly ferruginous layers that have been opened at several places in the search for iron ore.

The southernmost exposure in the river forms a little point about southwest of the south end of the island. It is a fine-grained pinkish-gray massive rock that resembles in texture many granulites. It is clearly bedded, and the beds are slightly contorted. In places it is apparently conglomeratic. Under the microscope the rock is seen to be an aggregate of grains of soda microcline and soda orthoclase cemented by a sparse cement composed mainly of sericite, fragments of feldspar, and a very small quantity of mosaic quartz. In addition there is a little hematite in streaks in the cement and in coatings on some of the feldspar grains. Most of the feldspar grains are crushed fragments, but here and there are rounded pieces that appear to be grains of sand, and in some places several fragments fit together in such a way as to reconstruct a rounded grain, many of which show strain shadows. The rock apparently is a crushed arkose.

On the west shore of the little island in the river, a few hundred yards north of the location of the specimen just described, is an exposure of bedded rocks striking about N. 35° E. and dipping 75° NW. at its south end, and striking N. 10° E. and dipping 70° NW. at its north end. At the top of the series is a light-gray fine-grained granitic rock in which, in many places, the feldspar is changed to green epidote. In thin section this rock is found to be a crushed granite, with an abundance of epidote, sphene, apatite, and green hornblende in the crush zones between large fragments of quartz, orthoclase, and a feldspar near oligoclase.

About 20 feet farther down in the series is a layer of about the same texture but of a slightly darker gray color. This under the microscope is found to be more thoroughly crushed than the upper layer, and it contains much more epidote, which is derived from feldspar and hornblende, and a little magnetite. In places it has been injected with pegmatite. Interbedded with it is another dark-gray fine-grained massive rock that looks under the microscope like a fine-grained facies of a gneiss intermediate between the Losee and Byram gneisses. (See pp. 49-50.) It consists of round light-green pyroxene grains, a few plates of bright-green amphibole, an abundance of microcline and some perthite, a very little quartz and calcite, and some epidote and sphene. The rock is crushed in streaks.

Interbedded with these two is a darker facies of the same rock in which there is a slight schistosity due to its penetration by tiny parallel veins of quartz and feldspar. In thin section all the original constituents seem to have disappeared, and in their places are pale hornblende, pale epidote, sporadic plates of biotite, and a few fragments of plagioclase and quartz in a fine-grained fibrous matrix of sericite, kaolin, talc, and perhaps serpentine.

About 30 feet lower, at the north end of the exposure, is a layer of amphibolite that is markedly schistose and very compact. Under the microscope large anhedrons of green hornblende, large plates of brown biotite, and equally large colorless areas representing plagioclase are seen to make up the greater part of the rock. Apatite and magnetite are also present. The colorless areas are now aggregates of small sericite fibers, residuals of a plagioclase near oligoclase, and

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a very little quartz. This is probably a slightly metamorphosed diorite.

A series of similar rocks, some of which are identical with those in the river, occur along the road on the east side of the river where it skirts the base of Marble Mountain. The road cuts expose highly dipping definitely layered schists extending almost continuously for a mile or more. Many of them are alternating layers of massive or very slightly schistose fine-grained material of slightly different colors, with the texture of granulites, in some places directly in contact and in others separated by thin seams of talcose or chloritic schists. Other layers are coarse-grained gneisses, others have the appearance of slightly schistose diabases or diorites, and still others are hornblendic schists. In these are little layers of comparatively coarse feldspar and quartz that apparently are small pegmatite veins. Here and there are comparatively thick layers of talcose schists and a few dark jaspery layers, and in one place near the north end of the exposure a layer or thin lens of sandy limestone has been opened by a small quarry. Beyond this and between it and the large quarry *(15)*[22] of the Rock Products Co., which is about half a mile distant, are other exposures of schists and gneisses not essentially different from those to the south.

The lens of sandy limestone near the north end of the exposure is a greenish-white marble with here and there a little pinkish patch that seems to indicate impregnation by granitic material. Immediately south of this limestone is a coarser-grained facies containing large grains of pink calcite and numerous flakes of black mica, and a few feet south of this is pegmatite. The finer-grained marble consists mainly of calcite and tremolite. Here and there are small grains of microperthite and quartz in streaks, but otherwise the rock is a schistose mass of granular and fibrous calcite and flakes of tremolite. Peck[23] gives analyses of two varieties of the limestone from this quarry as follows:

Partial analyses of limestone from quarry on east side of Delaware River 1½ miles north of Phillipsburg, N. J.

	1	2		1	2
SiO_2	48.40	0.28	CO_2	22.20	45.20
$Al_2O_3+Fe_2O_3$	5.96	2.38	Loss on ignition		.60
CaO	22.46	31.80			
MgO	.80	19.62		99.82	99.88

1. Coarsely granular siliceous limestone.
2. Pearl-gray dolomite.

[22] The numbers in parentheses following the names of mines and quarries in the text are the same as those on plate 5 indicating the positions of the openings.

[23] Peck, F. B., The talc deposits of Phillipsburg, N. J., and Easton, Pa.: New Jersey Geol. Survey Ann. Rept. for 1904, p. 182, 1905.

The marble at the quarry of the Rock Products Co. is sheared and slickensided to an extreme degree. Much of it is now a white talcose schist or a greenish-gray serpentine schist crossed by veins of coarse pink calcite and streaks of a colorless micaceous mineral in large flakes. Where not schistose it is a mass of calcite, bright-green serpentine, and tiny spangles of light-green or colorless mica, probably phlogopite, with a very small axial angle, a negative optical sign, and the plane of its optical axes perpendicular to 010. The "serpentine" is a mixture of fibrous talc and serpentine with rare embedded flakes of white mica, and a few small nests of calcite. The two prominent minerals are in large, thin, approximately parallel, rudely outlined lenses, but within the lenses the fibers of the talc are arranged indiscriminately, except in small areas in the thin section, where many small fibers lie approximately parallel across the long directions of what were once apparently mica flakes. The talc is, in part at least, an alteration product of the mica. The serpentine seems to be younger than the talc: at least narrow areas extend across areas occupied mainly by talc and enclose dissevered masses of this mineral.

In the more micaceous facies there is little or no talc. The greenish mica is partly changed to a uniform mass with a low birefringence resembling that of serpentine but showing no fibrosity. The outlines of the micas are well preserved, but within them are only a few thin brightly polarizing lamellae, crossing a nearly structureless mass of the serpentinelike material. The rest of the rock is a mixture of serpentine and calcite which occurs as a matrix for the altered micas. The two minerals are in nests and veinlets cutting each other indiscriminately. Some of the calcite is apparently infiltrated, and much of this later calcite is fibrous, with the fibers elongated perpendicular to the walls of the little cracks it fills.

A coarser-grained specimen in which the mica is in large colorless crystals, except near slickensides, where it is greenish, differs very little from the specimen just described except that the mica is less altered and consequently is brightly polarizing throughout.

Other sections show mainly talc surrounding plates of altered mica. With the talc is some fibrous serpentine and considerable calcite in nests and veins.

There are no igneous rocks in the quarry, consequently the mica, serpentine, and talc are probably to be regarded as the result of hydrothermal action along shearing planes.

Under the microscope all the schistose siliceous rocks along the road are seen to be crushed and some of them entirely recrystallized. The coarse gneiss is plainly a crushed pegmatite, composed mainly of quartz and microperthite, but with some orthoclase bordered by microcline. Some of the gneisses contain in addition to the quartz and feldspars a little hornblende and others some biotite, and all contain small amounts of magnetite. Chlorite is common in the debris of the crushed grains, which surrounds remnants of the quartz and feldspar.

The finer-grained, light-colored banded rocks, which in the hand specimen look like granulites, are composed mainly of quartz, microcline, and plagioclase with a little interstitial micaceous and chloritic material. As a rule the quartz is in grains with rounded outlines embedded in the feldspar and also in little veins cutting the feldspar. Between the adjacent feldspars are masses of a fine-grained aggregate composed principally of quartz. A little pyrite and magnetite and a few fragments of tourmaline are the only other minerals present in most specimens. In some specimens flakes of brown biotite cut through the other components. In others are flakes of muscovite, grains of garnet, sphene, zircon, and radiating clusters of rutile, and masses of hematite that appear to have replaced feldspar. In most of these rocks much of the feldspar is decomposed, and in many of them the interstitial aggregate is a mixture of kaolin, sericite, pale chlorite, and quartz. Although the interstitial substance in all the granulitic rocks is a completely crystalline aggregate, it nevertheless is much finer-grained than the large quartz and feldspars that make up the body of the rock and occupies the relation of a matrix in which the large grains are embedded. In other words, the appearance of the granulites suggests partly crushed quartz-feldspar rocks that have been recrystallized.

Medium coarse grained gray gneisses, some layered and others schistose, consist of quartz, microperthite, altered plagioclase which in many specimens is chloritized and saussuritized, streaks of fibrous green hornblende, and small amounts of magnetite, ilmenite, apatite, and sphene, zircon, or rutile. Many contain in addition microcline and others a fairly fresh plagioclase that is near oligoclase in composition. Many of the quartz grains show undulatory extinction, and many of the feldspars are crushed at their borders. Between the feldspar remnants and the quartz is a mosaic of fresh feldspar and quartz that may represent the recrystallization of fine fragments. In some specimens there are large prisms of tourmaline, and in others large anhedrons of hornblende partly changed to bright yellowish-green epidote. Many of the other members of the series contain biotite; some contain bright-green pyroxene, and some an abundance of epidote derived from pyroxene or hornblende. Most of them contain much sericite, chlorite, and sphene.

A few other rocks in the series are chlorite or sericite schists. All the members of the series show the effects of intense pressure, and in that respect they differ markedly from the Byram and Losee gneisses. Their quartz grains show strain shadows, and most of their larger grains of feldspar are shattered on their edges. Between these are masses of fine-grained aggregates made up of many quartz and feldspar grains, but they are not fragments. The components are intercrystallized, and with them are sericite, chlorite, epidote, and other secondary substances, besides in many specimens tourmaline, sphene, rutile, and zircon. Moreover, in most sections the large quartz and feldspar grains exhibit a different relation to one another from that shown in sections of granites and gneisses. The two are not intercrystallized, but the quartz is in rounded grains embedded in the large grains of feldspar.

It is evident that these rocks have been crushed and recrystallized, but whether those that are not distinctly crushed pegmatites were originally sedimentary or igneous is not so clear. Their even and repeated layering would suggest a sedimentary origin, but the fact that they contain so large a proportion of feldspar and so little quartz suggests that they are igneous rocks belonging to the granite and diorite series. It is possible, of course, that they may have been arkoses, but their variety and the thickness of the series throws considerable doubt on this view. The coarse gneisses were certainly pegmatites. It appears reasonable to infer that the series consists, at least partly, of quartzose alkalic rocks, a few diorites, and perhaps gabbros, altered by pegmatitic emanations. All have been crushed and recrystallized. In some places they have been sheared to hornblendic and biotitic schists, and in a few places to fine-grained platy schists composed largely of epidote, chlorite, and sericite. Although it is rarely possible to assign the rocks to any familiar plutonic type, many of them are similar to the Byram granite gneiss in chemical composition, though they differ from it in structure. The Byram gneiss is not layered and shows no evidences of being crushed. It is evident, therefore, that the rocks along the Delaware River are older than the Byram gneiss, and consequently also than the Losee gneiss, which may be contemporaneous with if not somewhat older than the Byram. They must, therefore, belong to the older series of rocks here called Pickering gneiss, which is believed to have been present when the Byram and Losee gneisses were intruded.

There are also distinct sedimentary beds in this older series. Reference has already been made to the limestone beds in the schists near the north end of the section (p. 26). Besides the limestone there are also in the midst of the gneisses and schists other layers of rocks that were originally sandstones and fine-grained conglomerates. These are now quartzite and quartzite conglomerates, some of which have been saturated with hematite (pl. 1, *B*). Other layers that are now slaty were probably once shales. These rocks are best exposed at the old Fulmer mine (II), at the southwest end of Marble Mountain well up toward its top. Here the hematitic beds were once mined as an iron ore, but without success. The quartzites associated with them are now completely crystallized quartz and hematite, with the hematite in curved streaks as if outlining sand grains. The slates consist mainly of an aggregate of sericite and chlorite fibers that are also crossed by curved lines of hematite particles. The areas enclosed by the lines of hematite have outlines of tiny lenses, as if they had been flattened grains. Zircon is commonly in some of the slates, and in others there is a large amount of tourmaline in long crystals and groups of crystals and in numerous slender spicules cutting through the micaceous mass. The large crystals are enlarged by the growth of a fringe of small crystals with their elongation perpendicular to the sides of the large crystals to which they are attached.

A few other layers associated with the ores may be either fine-grained sedimentary deposits or perhaps volcanic rocks. They are evenly banded, very fine grained, light-gray, dark-gray, or purple rocks and many of them seem to be saturated with feldspar. Where sheared they have become flaky, with the development of talcose minerals. Under the microscope they are discovered to be masses of talc and a small amount of quartz enclosing lenses of pink feldspar fragments.

There are only a few ledges of the talcose slaty rocks, fine-grained slates, quartzites, and quartz breccias or conglomerates on the hill, but the whole top of the west knob of the ridge has been honeycombed with test pits, the dumps of which carry an abundance of material for study. The best exhibition of the distinctly clastic rocks is in the old pit of the Fulmer mine. The walls of this pit reveal a series of layered slaty and quartzose rocks that are apparently interbedded. Some of them are distinctly schistose, but others exhibit only faint signs of schistosity.

The slaty rocks comprise very schistose light-yellow or gray schists containing a little talc and almost massive dense black jasperoid beds that look very much like ancient rhyolites. With these are interbedded a few layers of quartzite conglomerates, and enclosed in them are lenses of quartzite. A few of the beds are strongly ferruginous. The iron is mainly in the form of hematite, which in some places is almost uniformly distributed through the rocks and in others is segregated into disks and nodules. In many places garnet and tourmaline are present in both slates and quartzites. Tourmaline is especially noteworthy, as some of it occurs as black crystals 1 inch or more long and one-third of an inch thick. It is particularly abundant in very schistose phases of the slates.

Thin sections of the jasperoid rocks show grains of hematite and magnetite in an exceedingly fine-textured aggregate of chlorite and some micaceous mineral. In some sections there is a suggestion of diabasic texture in the arrangement of dark grains of magnetite in the lighter-colored micaceous aggregate. In others flow structure is suggested by the occurrence of the dark grains in curving and wavy streaks through the lighter matrix. On the other hand, a few sections show the dark grains in a series of parallel lines as if marking bedding, and in others lenses of the light aggregate are surrounded by hematite and magnetite as if representing pebbles in a matrix that has been replaced by iron oxides.

The general aspect of the slaty and jasperiod rocks is that of a series of interbedded sedimentary deposits and volcanic flows that have been squeezed and metamorphosed, but no decisive evidence can be cited to determine their origin. The rocks are strongly suggestive of the pre-Cambrian volcanic series of South Mountain, Pa.[24]

The quartzites and conglomerates differ only in the presence of lenses of white quartz in the conglomerates. Both are vitreous dark-gray rocks with a splintery fracture and a structure that shows no trace of foliation or schistosity. They range from very fine grained phases to those in which the particles measure several millimeters in diameter. In a few places they contain small subangular fragments of dense greenish-black rocks resembling the dark massive slates, but otherwise they possess no noteworthy features. The lenses of white quartz in the conglomerates range in size from particles as small as a pinhead to others 2 inches in diameter. Some are round, others lenticular, and others angular. The larger fragments are fractured as if crushed, and little tails of quartz mosaic extend from the ends of the lenses. The matrix in which these lie and the entire mass of the nonconglomeratic quartzites consist almost exclusively of quartz and hematite. The quartz is in small particles that may be sand particles, in little crescentic fragments, and in little lenticular masses of quartz mosaic, all of which lie in a finer-grained ground mass composed of quartz grains, hematite, and magnetite. In some thin sections there are also present a little secondary quartz and a few needles and large crystals of black tourmaline. All the rocks contain hematite, and it is to this constituent that their dark color is due. In some sections the hematite is in sinuous lines of particles, in others in circular lines of aggregates that surround quartz grains, and in still others in large compact irregular-shaped masses in the midst of quartz grains. It apparently was infiltrated.

Other rocks are intermediate between quartzites and slates. They are composed of grains of quartz in a schistose sericitic matrix in which are grains of hematite and large crystals of tourmaline and sparse fragments of rutile. With the sericite in the matrix are inter-

[24] Bascom, F., The ancient volcanic rocks of South Mountain, Pa.: U. S. Geol. Survey Bull. 136, 1896.

mingled a little chlorite and slender fibers of actinolite, and scattered through the aggregate is a dust of hematite, biotite, zircon, and other indeterminate minerals.

Rocks similar to these also occur on the dump of the old Titman shaft (III), about half a mile east of Bridgeville, N. J. Those are, however, so thoroughly weathered that their nature cannot be determined with surety. A belt of Hardyston quartzite flanks the hills south of the Pequest River, and the Titman shaft may be at the contact of the quartzite with the old gneisses. The single section that has been seen, however, shows that the rock has been very much more crushed and so much more altered than any specimen of the Hardyston quartzite examined that it is reasonably regarded as possibly pre-Cambrian.

In the Rock Products Co.'s quarry in the Franklin limestone on the east side of the river the rock is so sheared that much of it is a talc or a serpentine schist. (See p. 29.) The best exhibit of sheared phases of the limestone, however, is in the quarry (12) of the C. K. Williams Co. on the west side of the river about 1½ miles north of the highway bridge between Easton and Phillipsburg. Here the rocks are twisted, sheared, and fractured and are cut by pegmatite. It is probable that the pegmatite has had some effect in altering the limestone, but the greater effect was due probably to the dynamic processes, and the two effects cannot be distinguished. In places the rock of the quarry is a white marble containing here and there a tremolite crystal. In other places it is a gray and white mottled marble resembling in appearance a gray granite. This is interlayered with a few thin layers of a fine-grained dark-gray schist. The greater part of the rock is a light yellowish-green serpentine which, where compact, is a mixture of serpentine and calcite or a dark-green almost pure serpentine (analysis 2, p. 37). Where schistose the serpentinous rock is a mixture of light yellowish-green serpentine, flakes of white talc, and spangles of a yellowish-green micaceous mineral which very closely resembles the serpentine, except that it has a distinct cleavage. Where shearing is more intense the talc is increased in quantity, and a nearly pure talc schist results. On the other hand, in some places the micaceous mineral has replaced nearly all the other components and constitutes lenses of a coarse-grained aggregate of very light green, almost colorless mica plates, some of which measure as much as 1½ inches in diameter. The sparse filling between the crystals is serpentine. In other places, probably where the original limestone was less pure, the micaceous mineral is grayish green and more brittle, resembling very closely in appearance penninite or vermiculite, but analysis shows it to be a serpentinized phlogopite.

A sample of the nearly colorless mica carefully separated from serpentine (No. 1 in table) was analyzed by J. G. Fairchild, of the Federal Geological Survey, and found to be very similar to the white phlogopite from Edwards, N. Y.

Partial analyses of mica and phlogopite

	1	2	3		1	2	3
SiO_2	42.16	41.82	45.05	K_2O	9.96	6.08	8.52
Al_2O_3	11.08	11.12	11.25	LiO_2	-------	-------	.07
Fe_2O_3	} .58	{ -------	-------	H_2O	.00	.94	-------
FeO		2.68	.14	Loss on ignition	2.14	7.10	5.37
MgO	29.52	29.82	29.38	F	1.10	-------	-------
CaO	.00	-------	-------		96.84	99.92	100.23
Na_2O	.30	.36	.45				

1. White or light-greenish mica separated from serpentine, Verdolite quarry, near Easton, Pa. The sample was too small for reliable direct determinations of either water plus or of fluorine. Analyst, J. G. Fairchild.
2. White mica, Easton, Pa. Analyst, Charles Catlett: U. S. Geol. Surv. Bull. 419, p. 289, 1910. "Probably a vermiculite rather than a mica."
3. Phlogopite, peculiar nonfluoriferous variety, superficially resembling brucite. Talc mines, Edwards, St. Lawrence County, N. Y. Analyst, E. A. Schneider: U. S. Geol. Surv. Bull. 78, p. 24, 1891.

The phlogopite of Edwards (No. 3) is described by Penfield[25] as light sea-green in color and as giving a uniaxial interference figure or a "biaxial" figure with small axial angle. The plane of the optical axis is 010, and the double refraction is negative. It differs from the mineral from the Verdolite quarry in containing no fluorine. In all other essential respects the two minerals are similar except that the optical axial plane in the Easton mineral is perpendicular to 010.

A specimen of the serpentinized phlogopite that has been referred to as resembling penninite or vermiculite in appearance has the composition indicated below:

Analysis of serpentinized phlogopite from Verdolite quarry, near Easton, Pa.

	1	2		1	2
SiO_2	46.20	42.8	K_2O	4.54	4.9
Al_2O_3	5.59	5.5	H_2O-	.24	.00
Fe_2O_3	} 1.06	.3	H_2O+	5.72	7.5
FeO			F	.60	.55
MgO	33.95	36.5	CO_2	Present	---------
CaO	.00	.0		[1] 98.15	98.20
Na_2O	.25	.15			

[1] The low summation is due to the presence of some magnesite.

1. Altered phlogopite. Analyst, J. G. Fairchild.
2. Calculated composition of mixture composed of 50 percent phlogopite (analysis, above) and 50 percent pure serpentine. This is approximately the composition of the phlogopite half changed to serpentine.

In places where the more compact serpentine is crossed by little fault cracks the crevices are filled with slip-fiber chrysotile. Most of the cracks are very narrow, though some may be as wide as a

[25] Penfield, S. L., A very pure magnesia mica, phlogopite, from Edwards, St. Lawrence County, N. Y.: Am. Jour. Sci., 3d ser., vol. 36, p. 329–331, 1888.

quarter of an inch. Whether wide or narrow, the chrysotile that fills them is usually in fibers ranging in length between three-quarters of an inch and 1 inch. The contacts of the veins with their walls are very sharp, and there is no noticeable gradation between the rock and the vein filling. The serpentine grains in the layers forming the vein walls appear to have been drawn out into fibers. Where the slipping was along a crack—that is, where the shearing was localized—chrysotile was formed, but where the shearing involved rock masses—that is, where it was distributed over comparatively broad belts—talc was produced.

A few other veins crossing the serpentine consist of white fibrous calcite enclosing a few thin strands of chrysotile.

In some parts of the quarry are comparatively large masses of a mottled dark-green and red ophicalcite which formerly occurred in sufficient quantity to be quarried as an ornamental stone. The ground mass of the rock is a dark-green serpentine spangled with small glistening flakes of white mica and crossed by irregular veins of red dolomite, which here and there widen out to lenses composed of white calcite bordered by red dolomite. In thin section is seen a very confused mixture of serpentine, mica, and carbonate. The carbonate is in masses of about the same size as the mica plates and in small nests lying in the cleavage cracks of the mica and scattered through the bundles of serpentine fibers that constitute the greater part of the rock. It is all plainly infiltrated. The mica, where compact, has bright interference colors in sections that show the cleavage. Many crystals, however, are more or less crushed, and where badly crushed they polarize in blue and gray tints characteristic of serpentine. Where the crushing is not so severe, nuclei of brightly polarizing fibers are embedded in a mesh of serpentine fibers in such a way as to suggest that the change of the mica to the serpentine began at the cleavage cracks.

Peck [26] analyzed a piece of the "micaceous serpentine consisting of pseudomorphous serpentine after phlogopite" with the result below:

SiO_2	43.62
Al_2O_3 Fe_2O_3	4.39
MgO	40.78
CaO	.00
Alkalies	Undet.
Loss on ignition	9.95
	98.74

[26] Peck, F. B., The talc deposits of Phillipsburg, N. J., and Easton, Pa.: New Jersey Geol. Survey Ann. Rept. for 1904, p. 169, 1905.

Other phases of the metamorphosed limestone noted in this portion of the belt are described by Peck [27] but were not seen by the writer. One of these was a light-green serpentine with pinkish and flesh-red dolomite crystals, probably somewhat like the green and red ophicalcite referred to above. Another was a mixture of serpentine and tremolite, and the third a mixture of talc and tremolite cut by veins of apple-green serpentine. Thin sections of the last-named rock, according to Peck, show

> a felt-work of interlacing needles of tremolite, through which is scattered a subordinate amount of colorless or nearly colorless pyroxene, probably of the diopside variety. The tremolite shows all stages of alteration to talc, and the pyroxene changes to a cloudy and very light yellowish-brown serpentine.

A specimen of the serpentine-tremolite rock from the Verdolite quarry examined by Peck contained 2.2 percent of calcite, 61.5 percent of silicates soluble in hydrochloric acid, and 36.3 percent of insoluble silicates. The soluble portion had a composition approaching that of serpentine (No. 1 in table below), and the insoluble portion a composition (No. 3) suggesting to Peck a tremolite partly altered to talc.

Analyses of serpentine rocks from the Verdolite and Fox quarries, near Easton, Pa.

	1	A	2	3	B	C
SiO_2	42.98	43.5	42.94	60.15	57.7	63.5
Al_2O_3	2.30		3.76	1.64		
Fe_2O_3						
MgO	40.79	43.5	40.58	27.75	28.9	31.7
CaO			.67	8.52	13.4	
Alkalies				Undet.		
Loss on ignition	13.73	13.0	12.00			4.8
	99.80	100.0	99.95	98.06	100.0	100.0

Columns A, B, and C show the calculated composition of pure serpentine, tremolite, and talc, and No. 2 the result of the analysis by Peck [28] of a dark-green serpentine from the Fox quarry.

A complete list of the minerals occurring in the Verdolite quarry, as identified by Jewell Glass, of the Federal Geological Survey, is as follows:

Serpentine.	Talc.	Molybdenite.
Serpentine var. antigorite.	Calcite.	Hematite.
Tremolite.	Red dolomite.	Magnetite.
Kupfferite.	Siderite.	Uranium thorianite.[29]
Phlogopite (very light colored).	Diopside.	Uranophane.
Vermiculite.	Sphalerite.	Gummite (thorium-bearing).
	Zircon.	

[27] Peck, F. B., op. cit., pp. 173–174.

[28] Idem, pp. 172–174.

[29] Wells, R. C., Fairchild, J. G., and Ross, C. S., Thorianite from Easton, Pa.: Am. Jour. Sci., 5th ser., vol. 26, July 1933, pp. 45–54.

In discussing the metamorphism of the limestone, Peck concludes that wherever pegmatites intrude it the limestone becomes utterly changed in character. The contact effect of the intrusive

aided at least in building up in the latter [limestones] one or more silicates of lime and magnesia, such as tremolite, pyroxene, or phlogopite. Locally these silicates entirely replaced the original carbonates, but all intergradations can be found from nearly pure limestone or dolomite, containing but small amounts of the silicates, to rocks consisting wholly * * * of either pure-white tremolite or white pyroxene, or an aggregation of phlogopite mica scales, or mixtures of these different mineral species. * * *

Then followed the subsequent alteration of these silicates * * * to either serpentine or talc. In this alteration the tremendous forces which folded, squeezed, stretched, and faulted the rocks into their present position, together with the hydrating and leaching power of ever-present water, were the principal factors.[30]

To the writer the principal agencies in the production of much of the phlogopite as well as the talc, asbestos, and serpentine were dynamic. Some of the phlogopite is unquestionably a contact mineral, but much of it was formed in shear zones.

On the south slope of Chestnut Hill, west of the Verdolite quarry, the limestone was exposed nearly continuously from the Delaware River to a point within half a mile of the west margin of the Easton quadrangle, a distance of about 4 miles, by several quarry holes. Most of these quarries are now abandoned, but fortunately Peck[31] described them when they were active, so that in spite of the lack of exposures we have a record of the existence of the limestone in a continuous belt through most of this distance. At the west end of the area along Bushkill Creek the belt is duplicated near Walter's station by a narrow strip of marble about a quarter of a mile north of the main strip, where there is a little area about three-quarters of a mile long and a quarter of a mile wide entirely surrounded by Paleozoic sedimentary rocks. There are no outcrops of the limestone, but two quarries (*1* and *2*) near the road on the north side of the creek have been opened in a mass of white talc schist and a light-green serpentine. Southwest of the creek the talcose limestone is also exposed in the cellars of houses, but there are no natural exposures. A single isolated outcrop of a diabasic rock indicates that the limestone is cut by dikes in this area, as elsewhere. The same rock is associated with the talc schist in the quarries and in outcrops in the creek. Peck,[32] who visited the quarries soon after they were abandoned, described them as follows:

Here in a badly covered area * * * are two open pits * * * excavated in very much squeezed and fissile talcose rocks, ranging from very light-green, almost pure-white talc of a more or less fibrous or foliated character and

[30] Peck, F. B., op. cit., pp. 184–185.
[31] Idem, p. 163.
[32] Idem, p. 177.

of the best quality, through darker-green impure talcose rocks carrying much calcareous matter * * *, also pyrite cubes and dark mica scales and containing beds of fresh pearl-white tremolite. Immediately in contact with these talcose rocks and on the south side of them is a dark basic-looking rock, much jointed and contorted, apparently in the form of a sheet, dipping southward, but the disturbance has been too great to allow certain evidence.

He states that the rock is the same as that found in quarries half a mile farther east, on the south side of Chestnut Hill. He further states[33] that the dark rock can be traced by outcrops a quarter of a mile to the southwest and the talcose rocks by fragments in the soil both northeast and southwest, a distance of half a mile from the quarries.

The dark rock, which is probably intrusive in the limestone, where fresh and massive resembles a fine-grained dark greenish-gray dolerite. Most specimens, however, are schistose chloritic or hornblendic phases, like the well-known greenstone schists, and others are very distinct chlorite schists. The least-altered phase is a granular aggregate of bright-green pyroxene, microperthitic feldspar, and brown biotite, with a little apatite and magnetite as accessories. The pyroxene is greenish-yellow parallel to the single cleavage and emerald-green perpendicular thereto and has a maximum extinction of about 40°. Its composition as reported by Peck is that of an aegirite-augite. It is in large anhedrons with rounded outlines. Peck's analysis is quoted below.

Analysis of pyroxene from dark igneous rock associated with the Franklin limestone near Bushkill Creek, Easton, Pa.

SiO_2	50.55
$FeO.Fe_2O_3$	7.27
Al_2O_3	8.66
MgO	11.00
CaO	19.70
Na_2O	1.70
K_2O	.48
	99.36

The biotite is brownish yellow and dark greenish brown and has an extinction of about 1½°. It occurs in large isolated flakes embedded in the feldspar and in smaller ones in the feldspar near the borders of the pyroxene. The feldspars are a plagioclase near oligoclase, orthoclase, microperthite, and in some facies microcline. The plagioclase is in largest amount. It occurs as large anhedrons that are more or less altered to green hornblende and sericite, with here and there a little quartz and calcite. Peck states that the feldspar isolated by him contained 8.04 percent of K_2O and 4.55 percent of Na_2O. This must have been the microperthite, for most of the

[33] Peck, F. B., op. cit., p. 178.

feldspar in the sections seen by the writer is oligoclase, and the rock as a whole according to Peck contains only 2.37 percent of K_2O and 3.08 percent of Na_2O. Apatite and reddish-brown sphene are the only other minerals present in the rock, and these occur only in small quantity. The fabric of the rock is granitic, but the feldspars show a slight undulatory extinction. The striated plagioclase is more altered than the other feldspars, in many sections being much clouded, whereas the other feldspars are clear. In the more altered facies of the rock the pyroxene has entirely disappeared, and in its place is a fibrous felt of light-green amphibole crossed by little veins of magnetite and besprinkled with little grains of magnetite and hematite, and around the masses of felt are tufts of actinolitic amphibole extending out into the surrounding feldspar. The biotite is unchanged. The feldspars are crushed, and the debris contains much calcite as nests in the interstices between the fragments. Thin sections of the most altered facies show an almost uniform felt of pale-green sericite, in which lie fragments of apatite crystals, and small pieces of brown biotite that are split along their cleavage planes and frayed to sericite. The large plates of biotite characteristic of the massive rock are broken into many pieces scattered almost indiscriminately through the sericite felt. In the tiny spaces between the fibers of the felt is a clean, colorless matrix that may be albite.

An analysis of the rock by Peck gave the result shown in column 1.

Analysis of dark igneous rock associated with the Franklin limestone near Bushkill Creek, Easton, Pa.

	1	2	3		1	2	3
SiO_2	53.58	48.16	52.47	K_2O	2.37	2.79	2.26
Al_2O_3	13.56	12.85	12.15	H_2O	1.33	1.92	1.62
Fe_2O_3	1.48	2.79	3.47	TiO_2	--------	1.50	--------
FeO	4.75	7.11	5.23	P_2O_5	.17	.70	--------
MgO	8.93	10.45	9.94	Mn_3O_4	.92	MnO .14	CO_2 .54
CaO	8.20	8.13	9.71	Others	--------	.51	--------
Na_2O	3.08	3.18	2.81		98.37	100.23	100.20

1. Augite monzonite, near Walter's station, Easton, Pa. III.5.3.4.
2. Olivine basalt, Pilot Knob, Routt County, Colo. III.5.2.4. U. S. Geol. Survey Bull. 419, p. 118, 1910.
3. Diorite, Inchnadampf, Assynt, Scotland. III.5.3.4. Iddings: J. P., Igneous rocks, vol. 2, p. 222, 1913.

Peck called the rock an augite syenite, because of the presence in it of a notable quantity of orthoclase. Its analysis, however, indicates that it contains at least an equal amount of plagioclase and therefore might better be described as having the mineral composition of augite monzonite. In chemical composition it is a camptonose—that is, it has the chemical composition of some diorites and basalts. (See analyses 2 and 3.)

At the Rock Products Co.'s quarry (7) north of Easton, a similar rock is being quarried, but here it is badly crushed and its constituents are very much altered, epidote being the principal alteration product. All the pyroxene has disappeared, and in its place is a mass of large yellow-green grains of epidote in a matrix of hornblende and chlorite. The feldspar is also gone, epidote, chlorite, and a micaceous mineral taking its place. In spite of the crushing and the complete alteration of all the original components, the diabasic fabric of the original rock can still be discerned.

At the present time the relations of this siliceous rock to the limestone cannot be seen. It is evident, however, that a belt runs along the south side of the limestone at the southwest end of Chestnut Hill for at least a mile and another belt borders the south side of the talc and marble area at Walter's station. Only a few exposures of the rock were seen by the writer. One was at the Rock Products Co.'s pit north of Easton, where a few blasts have uncovered a ledge in an area that is generally underlain by marble. Others were on the south sides of the pits at Walter's station, another in the bed of Bushkill Creek, and another on the side of a road about a quarter of a mile southwest of the creek, but nowhere were contacts with the limestone seen. Peck, however, was more fortunate. He describes a section of 75 feet at Schweyer's quarry (*5*), at the southwest end of Chestnut Hill, as exhibiting a series of beds striking N. 55°–62° E. and dipping 55°–65° SE., consisting from north to south of 20 feet of coarse pegmatite, 20 feet of serpentine and tremolite, 10 feet of pearl-gray to white tremolite and calcite or dolomite, a thinner layer of a mixture of tremolite and serpentine, a dike of pegmatite, a thin layer of tremolite and serpentine, layers of micaceous or talcose marble containing an abundance of phlogopite plates, and finally a layer of dark-green basic-looking rock consisting of an aggregate of augite altered mostly to bluish-green hornblende, biotite, abundant plagioclase (albite), subordinate orthoclase, and much opaque substance that is probably magnetite. He describes the rock as scarcely distinguishable from the augite-orthoclase rock occurring at the old Wagner quarry, which is near the Rock Products pit, north of Easton, and at the pits near Walter's station. At the Wagner quarry the dark rock is mainly granular, in some places being coarse-grained and in others fine-grained. It consists of green augite (now mostly altered to uralite), orthoclase, microperthite, biotite, and magnetite. In a few places it is sheared to a chlorite schist.

Between the limestone at Walter's station and that on the south side of Chestnut Hill is the belt of gneisses and schists that constitutes the main mass of the ridge. Exposures are comparatively few except in the walls of the gorge cut by the Delaware River, in the railroad cut alongside Bushkill Creek, and at the road cut on the north side of the creek. Formerly a good section was exposed on the trolley road from Easton to the top of Chestnut Hill, but since the abandonment of the road the right-of-way has been overgrown and all the rocks have been covered. The rocks at the west end of the hill and along the trolley line are light-colored fine-grained gneisses interlaminated with the layers of dark hornblendic and micaceous gneisses and schists. Some of the light gneisses are granular white or light-green rocks resembling some facies of the Losee diorite gneiss, and the dark gneisses interlaminated with them are hornblendic and augitic rocks resembling some forms of the Pochuck gabbro gneiss. At the railroad cut alongside Bushkill Creek the gneisses are evenly layered rocks cut by pegmatite dikes. A few specimens examined microscopically are composed of fragments of fresh plagioclase, microcline, and orthoclase in a matrix consisting of a mass of epidote, saussurite, muscovite, hornblende, feldspar, and chlorite that may represent a decomposed orthoclase, grains of fairly compact green hornblende, and grains of sphene and of ilmenite surrounded by sphene borders. Other specimens are mainly microcline, microperthite, bright-green pyroxene, sphene, ilmenite, apatite, and large quantities of a yellow garnet that is evidently metamorphic. These rocks resemble closely the rocks on the east side of the Delaware River, which are regarded as portions of the Pickering gneiss.

The gneiss opposite Walter's station is a crushed mass of quartz, feldspar, biotite, hornblende, apatite, and magnetite. The feldspars are completely changed to micaceous alteration products, the biotite and hornblende to chlorite, and the whole rock is thoroughly saturated with quartz.

In the area west of Bushkill Creek the C. K. Williams Co. has recently opened a small quarry (*3*) in which the principal rock is a dark-green compact serpentine speckled with small black dots of limonite and tiny spangles of mica. Here and there it is cut by many parallel veins of a white chrysotile that is hardened by deposits of quartz between the fibers. In thin section the rock shows a mesh of serpentine fibers, in the midst of which are small flakes of a colorless micaceous mineral, many small rhombs of a carbonate, and a few serpentine fibers, in the midst of which are small flakes of a colorless micaceous mineral, many small rhombs of carbonate, and a few scattered irregular masses of limonite. The veins are composed partly of chrysotile and partly of a brightly polarizing, colorless fibrous mineral, but except in a few places they are rendered nearly opaque by a grayish-white deposit of what is apparently quartz.

STRUCTURE OF FRANKLIN LIMESTONE AND PICKERING GNEISS

At most of the smaller exposures of the Franklin limestone no definite stratification is noticeable. At the larger exposures, however, in nearly all cases a more or less distinct bedding is observable. This was true of the limestone area between Hazen and Pequest before the old mine pits were abandoned. Here the strikes and dips indicated folding which is best expressed by the variations in the strikes and dips of the ledges southwest of the Raub mine. There are, however, not enough exposures to warrant any definite conclusions as to the structure in detail. It is possible that the present boundaries of the area are due to faulting, as slickensides are abundant on the walls of the ore body at the Ahles mine and evidence of shearing has been noted in the ledges along the northern border of the area.

The small areas of the Franklin limestone near Roxburg probably represent lenses in the gneisses.

The layered schists and gneisses closely associated with the Franklin limestone and herein assigned to the Pickering gneiss are so badly sheared that it is difficult to follow them continuously for any great distance along their strikes. So far as can be learned the layers are flat lenses many times longer than they are thick. Their strikes are conformable with the strikes of the Byram and Losee gneisses in their vicinity, and their dips are the same. The plotting of the strikes and dips shows clearly that the series is folded into close folds with axes striking in general northeast, but a more accurate determination of the character of the folding is impossible because the same layers cannot be identified on opposite sides of the axial planes. The conformity between the dips and strikes of the Pickering schists and gneisses and those of the Byram and Losee gneisses is thought to be due to the fact that the latter are igneous rocks that were intruded between the layers of preexisting Franklin limestone and Pickering gneiss. In some places the intrusive probably made space for itself by dissolving portions of the preexisting rocks, thus giving rise to facies which differ in character from the main mass.

RELATIONS OF FRANKLIN LIMESTONE AND PICKERING GNEISS TO SURROUNDING ROCKS

The Franklin limestone is cut by pegmatite dikes and by dioritic masses that are similar in appearance to many of the more massive bands of Pochuck gabbro gneiss. The dioritic intrusions where in contact with limestone are in part scapolitic, the scapolite replacing all or a great portion of the plagioclase in a rock that is otherwise a diorite. In a few places in other parts of the Highlands the formation is intruded also by distinct dikes of diabase that are believed to be apophyses of the great masses of Triassic diabase south of the Highlands area. In the Delaware Water Gap quadrangle it is cut also by veins of sphalerite and encloses magnetite-limonite ore bodies.

The relations of the Franklin limestone and associated Pickering gneisses and schists to the Byram, Pochuck, and Losee gneisses is not so clear. The schists are so like some phases of the Pochuck, Byram, and Losee gneisses that it is impossible in most places to determine the relations between them. In other places layers of gneisses like the Byram, Losee, and Pochuck are interleaved with schists that are quite different in character. In these places the Pochuck, Byram, and Losee gneisses are apparently intrusive in the schists. The most profoundly metamorphosed black layers are believed to be parts of the older Pickering gneiss. (See also pp. 12–19.) Where the Franklin limestone is closely associated with the gneisses the relations are a little clearer but not decisive. In most places the limestone is entirely surrounded by gneiss. It usually occurs in small areas that are elongated in the direction of the schistosity and of the banding in the gneisses. Moreover, mine pits appear to show that the limestone extends downward a long distance as narrow plates or lenses interlaminated with the gneiss. It is this relation, which is a common one throughout the Highlands, that has led many geologists to regard the phenomenon as interbedding and the limestone and gneisses as interstratified members of a series of sediments.

Contacts between the limestone and the gneisses are extremely rare, and nowhere are they sufficiently characteristic to establish the relations between the rocks. In view of the fact, however, that the rocks are cut by pegmatites that are believed to be connected genetically with the gneisses (p. 53), and in a few places by masses of black rock resembling some of the dark gneisses here described as Pochuck gabbro gneiss, it is inferred that the Franklin limestone is older than the light-colored quartzose gneisses and some of the dark gneisses and that these rocks are intrusive into it. Moreover, in some portions of the district narrow seams of siliceous rocks are apparently interlayered with the limestone. As these seams have the mineral composition of some forms of the Byram and Losee gneisses, it is thought that they represent small tongues intruded into the limestone parallel to the bedding.

There is no place within the present area where the relations between the Franklin limestone and the overlying Hardyston quartzite are observable, but in other portions of the Highlands these relations are so plain as to leave no doubt that the Franklin limestone lies unconformably beneath the quartzite. One of the most noticeable features of the two formations wherever both are observable is the presence of pegmatite and diorite in the limestone series and their absence from the quartzite. In the Delaware Water Gap quadrangle this contrast is not noticeable because of the lack of exposures of the two formations in near conjunction, but in other portions of the Highlands the difference is so marked that no doubt of the relationship can legitimately be entertained.[34]

Moreover, the Hardyston quartzite is not markedly schistose except very close to faults, whereas the Franklin limestone and underlying Pickering gneiss are sheared or shattered, their components are

[34] U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), p. 3, 1908.

crushed, or recrystallized, and most of their original constituents have been changed to secondary minerals. They thus exhibit the effects of a profound deformation which the quartzite has escaped. The Franklin limestone, moreover, in many places contains metamorphic minerals, whereas the Hardyston quartzite is free from them.

AGE OF FRANKLIN LIMESTONE AND PICKERING GNEISS

From the discussion of the relations of the Franklin limestone and Pickering gneiss to the Pochuck, Byram, and Losee gneisses and the Hardyston quartzite it is apparent that the limestone and Pickering gneiss are older than the other gneisses. The Franklin lies unconformably beneath the Hardyston quartzite and is intruded by the Pochuck, Byram, and Losee gneisses. Whether the Franklin and Pickering should be regarded as late pre-Cambrian or as early pre-Cambrian has not yet been determined with certainty. In most of the area that has been studied there have been no facts observed that would serve as a means of separating the pre-Cambrian rocks into a younger and an older series, and until some such facts are obtained it is possible only to declare that they are pre-Cambrian. At the Andover mine, in the Franklin Furnace quadrangle, and at Marble Mountain, on the Delaware River, however, there are series of quartzites and conglomerates that are here considered to be a part of the Pickering gneiss. The existence of these rocks indicates clearly that at the time the Franklin limestone was laid down there was a land area that was furnishing sand and pebbles. Although no traces of this land have yet been found in the Highlands, its former presence is assured through the evidence of the rocks laid down off its shore. If the conglomerates and quartzites are parts of the Pickering gneiss then it and the Franklin limestone must be considered as of late pre-Cambrian age. A more precise determination of age is impossible, unless it is assumed that the presence of the limestone in the sedimentary series permits correlation with the Grenville of Ontario. On this assumption, when the age of the Grenville is definitely fixed, that of the Franklin limestone and Pickering gneiss will be known.

For many years the prevailing opinion among geologists who had personally investigated the Franklin limestone was to the effect that it is a metamorphosed phase of the Kittatinny limestone (Upper Cambrian and Lower Ordovician). This view, however, was successfully disproved by Westgate [35] in 1894 and by Wolff and Brooks [36] in 1898.

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[35] Westgate, L. G., The age of the crystalline limestones of Warren County, N. J.: Am. Geologist, vol. 14, No. 6, pp. 369–379, December 1894.

[36] Wolff, J. E., and Brooks, A. H., The age of the Franklin white limestone of Sussex County, N. J.: U. S. Geol. Survey 18th Ann. Rept., pt. 2, pp. 431–457, 1898.

INTRUSIVE GNEISSES

GENERAL FEATURES

The greater part of the Highland ridges are underlain by the three intrusive gneisses to which reference has already been made—namely, Pochuck gabbro gneiss, Byram granite gneiss, and Losee diorite gneiss. The gneisses grade into one another through intermediate forms, but there are at least the three distinct types, which as a rule can be recognized easily in thin sections under the microscope, although they may not be distinguishable everywhere in the field. One of the types is the black rock here called Pochuck gabbro gneiss and the other two are light rocks, here called Byram granite gneiss and Losee diorite gneiss.

The gneisses occur in tabular masses or thin lenses which on the surface appear as belts. In some places several kinds of gneisses are interleaved in approximately equal proportion in layers of nearly equal thickness, and the outcrops appear banded. This is the arrangement in Jenny Jump Mountain, where the lenses are comparatively long and narrow, and the outcrop is consequently marked by strips of different colors, which wedge out at their ends. In other places the lenses of the less prominent gneiss are so short that the outcrop as a whole appears mottled rather than banded, and in still other places the lenses are so broad that large areas are occupied by a gneiss of a single type. In the area under discussion the lenses are broad, except on Jenny Jump Mountain, and the ridges show a homogeneous type over large areas.

Moreover, in many places there are in the areas otherwise occupied by the gneisses small exposures of limestone, dark and light schists, garnetiferous gneisses, and other schistose rocks that are believed to belong to the Franklin limestone and Pickering gneiss, but they are so small that few of them are mapped.

Because of the general intermingling of the different gneisses, the mapping of the gneiss areas is based on the dominant type; consequently the areal delineation of the individual types is largely arbitrary, the gneisses of intermediate character being included with the type to which they are believed to be allied most closely.

As the Losee, Pochuck, and Byram gneisses correspond closely in mineral and chemical composition to some varieties of granites and diorites, as they exhibit no traces of sand grains in thin sections, and as in some places they show irregular crosscutting contacts, they are assumed to be of igneous origin. Large amounts of preexisting rock material may have been more or less completely assimilated by the invading magmas, and some of the intermediate phases of the gneisses may be due to this fact.

In all the gneisses the schistosity is the result of the nearly parallel arrangement of the elongated forms of the component mineral grains. This is believed to be due to the crystallization of the rock magma under differential pressure. Elsewhere in some pre-Cambrian gneisses, notably in northern New York and eastern Canada, schistosity occurs in different stages of development, showing clearly that it is the result of crushing and other secondary processes. Throughout the Highland belt, however, evidence of crushing in the components of the gneisses is lacking except in certain narrow zones that are regarded as fault zones. The structure is therefore believed to be original. (See pl. 3, *A*, *B*.)

Both the interbanding of the gneisses and their schistosity or perhaps, better, their linear structure were produced before the deposition of the Hardyston quartzite, as fragments of the banded and linear gneisses occur in the conglomeratic portions of the quartzite. These gneisses are therefore pre-Cambrian. Their distribution in belts conforming in strike with the Franklin limestone and Pickering gneiss and their linear structure are both explained as a result of their intrusion into those formations along the paths of least resistance—that is, along their schistose and bedding planes. (See pl. 2.) If the Franklin was already schistose when the intrusions took place, the gneisses must be regarded as post-Franklin; if intrusion occurred contemporaneously with the production of schistosity, or if intrusion and schistosity were both results of the same process of deformation, the gneisses must be regarded as having been intruded at the end of Franklin time. That these gneisses are younger than the Franklin limestone and associated sedimentary rocks herein called Pickering gneiss is indicated by the presence of small areas of these rocks in the gneisses, and by the further fact that some of the areas of limestone are merely the outcrops of small masses of this rock that are surrounded on all sides and beneath by the gneisses. Moreover, the sedimentary Pickering gneiss is badly crushed, while the intrusive gneisses show no signs of crushing, except in fault zones.

POCHUCK GABBRO GNEISS

The formation to which the name "Pochuck gabbro gneiss" is herein applied is a black or dark-gray rock with the chemical composition of many diorites and gabbros, but differing from them mineralogically in containing orthoclase, microcline, and oligoclase rather than the more basic plagioclases. It is considered to be older than the more granitoid Byram and Losee gneisses. The dark rocks of the Pochuck are nearly everywhere foliated and are interlaminated with thin sheets of the Losee diorite gneiss and broadly interleaved with both the Losee and Byram gneisses. The Franklin limestone is similarly interleaved with the granitoid gneisses, so that the dark gneiss and the white limestone together seem to constitute a matrix enclosing the light gneisses (Byram and Losee). If this is so, these dark gneisses are older than the light ones. They may be the equivalents of the black schists in the late pre-Cambrian gneisses of the West Point quadrangle, which in the table of correlations in the report of Knopf and Jonas[37] are stated to be possible equivalents of hornblende schist layers in the Baltimore gneiss, which is classed as early pre-Cambrian.

The dark gneiss that is older than the other gneisses is now generally accepted as consisting of calcareous sedimentary rocks entirely recrystallized by dynamic metamorphism or through the influence of the Pochuck, Losee, and Byram magmas.

In a few places in the Raritan and Franklin Furnace quadrangles the more massive phases of the dark gneiss are intrusive in the limestone, and at certain places near magnetite mines thin seams of hornblende rocks apparently intrude Losee and Byram gneisses and are probably younger. Moreover, at a few places where the dark gneiss intrudes the limestone its feldspar has been changed to scapolite, indicating endomorphous contact action, due probably to the solution of limestone fragments in the dioritic magma.

The Pochuck gabbro gneiss is probably a basic differentiate of the magmas that yielded the Byram and Losee gneisses, as its mineral composition varies from place to place and is closely related to that of the variety of light gneiss with which it is associated. There are gradational phases between some of the Pochuck gabbro gneiss and both of the other gneisses, and these intermediate layers are interleaved with pure types of both of the light-colored gneisses. However, Spencer[38] found the Pochuck gneiss intruded by the Losee gneiss in the Franklin Furnace quadrangle, and the writer[39] found sharp-edged masses of the black gneiss in the Byram gneiss in the Raritan quadrangle. These were regarded as inclusions, and their presence in the Byram gneiss was thought to indicate that some of the Pochuck rocks were solid when the Byram was intruded. The observations of Spencer and Bayley would seem to point to existence of one type of Pochuck gneiss that is older than both the light-colored gneisses.

In some places, however, the dark minerals in the Byram gneiss coalesce into large flat lenses whose composition is identical with that of some of the Pochuck layers interlaminated with the Byram gneiss. Consequently, some of the layers of Pochuck gneiss may be contemporaneous with part of the Byram gneiss, and as the Losee gneiss

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[37] Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pa.: U. S. Geol. Survey Bull. 799, p. 68, 1929.

[38] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), p. 4, 1908.

[39] Bayley, W. S., U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 8, 1914.

may be of the same approximate age as the Byram gneiss, it should follow that the three gneisses are phases of a continuous series of intrusions.

The Pochuck gneiss as heretofore defined includes two groups of dark gneisses of different age and different origin, one group comprising sedimentary gneisses that are older than the Byram and Losee types and of pre-Franklin age, and the other comprising igneous rocks that may be differentiates of the Byram and Losee magmas. The two groups have not yet been mapped separately anywhere in the Highland belt, because of the difficulty of discriminating between them. In this report the name "Pochuck" is restricted to the igneous rock, and the older dark- and light-colored schists and gneisses and slaty rocks of sedimentary origin are here mapped and described as Pickering gneiss.

All the rocks included in the Pochuck gabbro gneiss are dark-colored, and most of them are black. They are composed of different proportions of oligoclase, orthoclase, microcline, microperthite, diopside, hornblende, hypersthene, biotite, magnetite, and quartz. At a few other places, where the rock is in contact with limestone, all or nearly all of its feldspar is replaced by scapolite. The scapolitic varieties are, however, not known in this district.

Where the Pochuck gneiss is associated with the Losee diorite gneiss oligoclase is the principal feldspar of the Pochuck and diopside is abundant. Where it is closely associated with the Byram gneiss, however, microperthite and microcline are prominent in the black gneiss and hornblende exceeds diopside. An analysis of a specimen of the Pochuck gneiss from the Pardee mine, in the Greenwood Lake quadrangle, near Green Pond, shows that this specimen is similar in composition to a norite from the Kent mine, Elizabethtown, N. Y. The norm falls in the group camptonose (III.5.3.4). in the quantitative system—a group that includes many gabbros and some diorites.[40]

The structure of the dark gneisses ranges from massive to very gneissic. The massive varieties are granular crystalline rocks closely resembling coarse-grained gabbros. This type occurs principally as intrusions in the Franklin limestone and is unquestionably an igneous rock that has been somewhat metamorphosed by dynamic processes.

LOSEE DIORITE GNEISS

The Losee diorite gneiss is in general a light-colored rock which where only superficially weathered is white and where deeply weathered is bronze-colored, like much of the weathered Byram granite gneiss. All gradations exist between the Losee gneiss and

[40] In the text of the Raritan folio, p. 87, this rock is wrongly designated auvergnose.

the other gneisses, but what is regarded as the pure type is well characterized, especially under the microscope, by the presence of orthoclase and oligoclase. The prominent feldspars of the Byram gneiss are microcline and microperthite.

The Losee gneiss consists mainly of oligoclase and quartz, smaller amounts of orthoclase, bright-green diopside, with hornblende, hypersthene, biotite, apatite, magnetite, sphene, and locally zircon in varying proportions (pl. 3, *A*). With decrease in oligoclase the Losee phases pass into the Byram phases and with increase in pyroxene and hornblende into phases of the Pochuck gabbro gneiss. Mineralogically the more typical variety is a quartz monzonite. Chemically it falls into the group noyangose (I.4.1.5), in which are also many soda granites.

BYRAM GRANITE GNEISS

The Byram granite gneiss embraces several phases that differ greatly in appearance. Of the two principal varieties one is dark gray and moderately coarse grained and has a bronze tone on freshly fractured surfaces. The other is yellowish in outcrop and is pink, light gray, or nearly white on fresh fractures. Between these are intermediate phases with intermediate characteristics. All varieties are composed of microperthite, microcline, orthoclase, hornblende, quartz, magnetite, apatite, and sphene in varying proportions. The dark components in the darker phases are commonly grouped into pencils with their long axes striking with the rock bands and pitching in the same direction as the axes of the ore bodies in the magnetite mines in their neighborhood. Hand specimens are therefore gneissoid on all fracture surfaces except that transverse to the axes of the pencils, where the structure appears evenly granular. The lighter variety differs from the darker one mainly in the subordination of dark components and the lack of the dark pencils. It may exhibit a slight linear structure, but that is so obscure that most of the rock is practically granitic (pl. 3, *B*).

Analyses of a light-gray phase and of a pinkish-gray micaceous variety are published in the Raritan folio. The first is a tehamose (I.3.2.3) and the second an ilmenose (II.5.1.3), as defined by the quantitative chemical classification, and therefore they are similar in composition to many plutonic rocks that have been described as granites and syenites, or if it is desired to emphasize the alkalic nature of the rocks the first may be called a sodipotassic granite and the second a sodipotassic syenite.

The structure of the Byram gneiss is in general like that of a plutonic rock that has crystallized under conditions of differential stress.[41] Its occurrence in lenses or thin layers is probably due to the fact that it intruded a series of schistose or bedded rocks (Franklin limestone and Pickering gneiss) parallel to their structure. In other words, it is thought that the distribution of the Byram gneiss was determined by the distribution of the rock series it invaded.[42]

CHEMICAL RELATIONS OF THE SEVERAL GNEISSES

The following table shows that specimens of the various gneisses representing phases differing widely in appearance are so closely related chemically and exhibit such gradual transitions into one another that it is reasonable to regard the light gneisses and some of the black gneisses as differentiates of the same mother magma. Others of the black gneisses may be altered sediments.

Norms of the gneisses of the Highlands

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	------	1.98	32.76	32.04	39.12	35.10	33.72	36.54	36.78	39.42	43.98	2.28	3.66
Orthoclase	6.67	3.34	7.23	15.57	22.24	27.80	27.80	27.24	35.03	24.46	31.14	31.69	28.36
Albite	15.20	34.58	56.07	41.39	28.82	28.30	30.39	26.20	19.91	28.82	13.62	48.21	49.50
Anorthite	16.40	43.37	3.61	8.34	1.95	4.45	4.45	5.56	4.17	3.89	3.89	1.39	8.06
Nepheline	5.11	------	------	------	------	------	------	------	------	------	------	------	------
Corundum	------	------	------	1.43	2.35	1.53	2.04	.41	.82	1.12	.71	1.43	.15
Apatite	.40	.34	.06	------	------	------	------	------	------	.17	------	.34	.34
Calcite	.45	.60	------	------	------	------	------	------	------	------	------	.30	.90
Water	1.33	1.22	.33	------	------	------	------	------	------	.85	------	1.08	.87
Diopside	33.05	3.53	------	------	------	------	------	------	------	------	------	------	------
Hypersthene	------	8.46	------	1.12	.30	1.16	1.42	1.16	1.29	.66	4.48	4.15	4.23
Olivine	7.72	------	------	------	------	------	------	------	------	------	------	------	------
Magnetite	9.51	1.86	.23	.23	3.02	1.16	.23	2.32	.93	.93	.23	7.66	4.41
Ilmenite	4.26	.76	.30	.15	.91	.15	.30	.61	.46	.15	1.22	1.22	------
	100.10	100.04	100.59	100.27	98.71	99.65	100.35	100.04	99.39	100.47	99.27	99.75	100.48

1. Pochuck gabbro gneiss, Pardee mine, Green Lake, Greenwood Lake quadrangle. U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), p. 4, 1908. Camptonose (III.5.3.4).
2. Augitic facies of Losee diorite gneiss. Gradation toward Pochuck gabbro gneiss. Near Davenport mine, west of Berkshire Valley, Raritan quadrangle. U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 8, 1914. Hessose (II.5.4.3).
3. White Losee diorite gneiss, knob northeast of Berkshire Valley, Raritan quadrangle. U. S. Geol. Survey Geol. Atlas, Passaic folio (No. 157), p. 5, 1908. Noyangose (I.4.1.5).
4. White granite gneiss, quarry 1 mile south of Cranberry Lake, Raritan quadrangle. Lewis, J. V., New Jersey Geol. Survey Ann. Rept. for 1908, p. 74. Intermediate between Byram and Losee gneisses. Lassenose (I.4.2.4.).
5. Gray granite gneiss, Di Laura's quarry, near Haskell, Greenwood Lake quadrangle. Lewis, J. V., idem, p. 67. Intermediate between Losee and Byram gneisses. Alaskose (I.3.1.3).
6. Pinkish-gray granite gneiss, Allen quarry, three-quarters of a mile northeast of Waterloo, Raritan quadrangle. Lewis, J. V., idem, p. 72. Intermediate between Losee and Byram gneisses. Toscanose (I.4.2.3).
7. Light-gray granite gneiss, quarry 2 miles north of Waterloo, Raritan quadrangle. Lewis, J. V., idem, p. 73. Nearly identical with No. 6. Toscanose (I.4.2.3).
8. Light-gray gneiss, Kice's quarry, Schooley Mountain, three-quarters of a mile west of German Valley, Raritan quadrangle. Lewis, J. V., idem, p. 77. Byram granite gneiss. Tehamose (I.3.2.3).
9. Pink granite gneiss, half a mile east of Charlotteburg, Greenwood Lake quadrangle. Lewis, J. V., idem, p. 68. Byram granite gneiss. Tehamose (I.3.2.3).
10. Light-colored Byram granite gneiss, quarry 1 mile west of Hibernia, Raritan quadrangle. U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 5, 1914. Tehamose (I.3.2.3).
11. Byram granite gneiss inclusions in pegmatite, quarry at Pompton Junction, Greenwood Lake quadrangle. Lewis, J. V., op. cit., p. 66. Mihalose (I. 3.2.2).
12. Micaceous facies of Byram granite gneiss, pinkish-gray, approaching Pochuck gabbro gneiss, Van Nest tunnel, Oxford. U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 9, 1914. Ilmenose (II.5.1.3).
13. Gneiss, intermediate between Losee diorite gneiss and Pochuck gabbro gneiss, Van Nest tunnel near Oxford, Raritan quadrangle. Idem, p. 9. Laurvikose (I. 5.2.4).

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[41] Wright, F. E., Schistosity by crystallization—a qualitative proof: Am. Jour. Sci., 3d ser., vol. 22, p. 224, 1906.

[42] Fenner, C. N., The modes of formation of certain gneisses in the Highlands of New Jersey: Jour. Geology, vol. 22, pp. 594, 694, 1914.

PEGMATITES

GENERAL CHARACTER AND DISTRIBUTION

Pegmatite is found in large quantity associated with all the other rocks of the Highlands, and in some places it covers considerable areas unmixed with other rocks. Although commonly occurring in sheets or layers running parallel to the associated limestones and gneisses, in some places it forms veinlike bodies cutting across the structure of these rocks and penetrating them in such a way as to leave no doubt that it is distinctly younger. In several localities pegmatite masses that are intercalated between gneiss bands and run parallel with them for long distances send off branches which leave the main masses at approximately right angles and traverse the gneiss nearly perpendicular to its strike.

No attempt has been made to map the pegmatite dikes in any portion of the Highlands except where they cut the Franklin limestone in the Franklin Furnace quadrangle. They are, however, present at many places in the gneisses but usually in bodies so small that they could not be represented on a map of small scale without undue exaggeration. The largest mass in the area under discussion is a great dike 50 feet wide that forms the crest and western slope of Ragged Mountain, the sharp ridge 1½ miles south of Roxburg, and extends for several miles to the southwest.

COMPOSITION AND AGE

The principal minerals of the pegmatite in the Byram and Losee gneisses are the same as those in the gneisses—namely, quartz, microcline, microperthite, oligoclase, hornblende, pyroxene, biotite, in many places magnetite and graphite, and in some places muscovite. The hornblende and pyroxene vary greatly in quantity, here and there forming more than half of the rock mass. Hornblende is especially abundant in many dikes, especially those that are associated with the magnetite ores, and it occurs in large crystals, some of which measure 12 or 15 inches in length. Garnet is a common constituent, more particularly in the few places where the rock has been sheared. Apatite, sphene, and zircon are also present in many occurrences, much of the zircon in fine crystals. In some of the pegmatite bodies the proportion of the magnetite present is so great that the rock has been mined as lean iron ore. Graphite, which is abundant in some of the pegmatites in other portions of the Highlands, has not been seen in any dike in the Delaware Water Gap quadrangle.

The composition of the pegmatite bodies in the gneisses suggests that they are closely allied to the gneisses genetically. Considerable force is added to the suggestion by the facts that their chief feldspar is, as a rule, like that of the gneisses through which they cut; that in many places pegmatite and gneiss grade into each other without any sharp line of contact; and that in other places there are very coarse-grained patches in the gneisses that are unquestionably identical in character with much of the pegmatite. Hence it is inferred that the pegmatite is a product of the magmas that produced the gneisses. The pegmatites that cut across the structure of the gneisses must be younger than the gneisses which they traverse. As these pegmatites are like those that are not demonstrably intrusive, it is inferred that the latter are also younger than the gneisses and that all the pegmatites in the gneisses are intrusive portions of a deep-seated magma, the earlier invasions of which gave rise to the Byram and Losee gneisses.

Although many of the pegmatites cutting the Franklin limestone are like those associated with the Byram and Losee gneisses, there are others that are different. Some are characterized by the presence of very little quartz, and others by the presence of notable amounts of quartz and muscovite. The varieties containing only very small amounts of quartz are composed mainly of alkali feldspars, largely microcline and microperthite, some sericitic mica, and a little chloritized amphibole. They are properly syenite pegmatites. The muscovite varieties are of ordinary types. Both kinds are crushed and sheared, and both contain garnets and in many places tourmaline. Their composition distinguishes them from the pegmatites associated only with the intrusive gneisses and indicates for them a different origin; and the fact that they are crushed and sheared, even when not in fault zones, suggests that they are older than the pegmatites cutting the gneisses, which are schistose only where in or near crush zones in the gneisses. It is possible that they are genetically related to some of the intrusives that were metamorphosed and now constitute the Pickering gneiss.

ECONOMIC GEOLOGY

ECONOMIC PRODUCTS

The principal economic products obtained from the pre-Cambrian rocks of the two quadrangles are magnetic iron ore, marble used as a flux and in the manufacture of portland cement, and serpentine and talcose rocks used for paper filter, stucco, terrazzo, and roofing. A part of the serpentine has been quarried for interior decoration, and some of the best of the talcose rocks are crushed to "flour." In addition some limonite comes from the lower portion of the Paleozoic beds near their contact with the pre-Cambrian. Most of the limonite was formerly used as an iron ore. None is now being produced for ore, but a small quantity is being mined for paint.

Some of the Paleozoic limestone and shale is used for cement. The Kittatinny limestone is employed as a building stone.

At present the production of mineral substances is at a low ebb. Most of the mines and many of the quarries that were active 25 or 30 years ago have been abandoned.

MAGNETITE

MINE OPENINGS

Magnetite has been observed at many places in the pre-Cambrian rocks of the Delaware Water Gap and Easton quadrangles, but only at a comparatively few places has it been found in sufficient quantity to be mined with profit. About 29 openings on the New Jersey side of the river have yielded ore, but of these only about 14 have produced it in merchantable quantity, and only 6 of these developed into active mines. In 1923 only the Washington mine was being operated. This mine has since been abandoned.

The following list includes the names of all mines that have shipped magnetite ore in the past. Not all were active at any one time, and some of them were operated for a single year only.

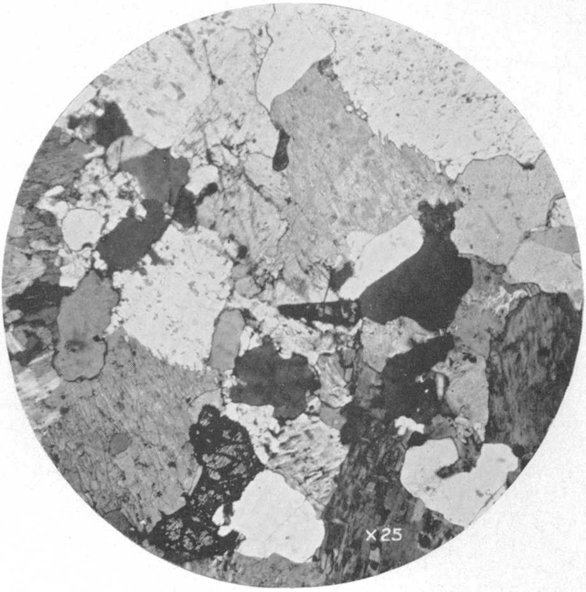
- Roseberry, 2 miles south of Belvidere.
- Barton, half a mile southwest of Hazen post office.
- Little, 1½ miles east of Hazen post office.
- Queen, 1½ miles east of Hazen post office.
- Riddle, 1¾ miles east of Hazen post office.
- Osmun, 1¼ miles south of Buttzville.
- Ahles, 1½ miles south of Buttzville.
- Harrison, 3 miles south of Buttzville and three-quarters of a mile southwest of Oxford.
- Washington, 3 miles south of Buttzville and three-quarters of a mile southwest of Oxford.
- Carter, 2 miles west of north of Stewartsville.
- Swayze, three-quarters of a mile east of West Portal.
- Wildcat, half a mile southeast of West Portal.
- West End, half a mile southwest of West Portal.
- Hager, 1 mile west of Spring Mills.

The other openings at which more or less magnetite was found were known as the Raub, Shoemaker Farm, Brewer, Kaiser, Cline, Henry, Case, Martin, Wright, Petty, Duckworth Farm, Sinclair, and Hart. At some of these several hundred tons of ore was obtained, but at none was it thought worth while to continue operations for more than a few months.

On the Pennsylvania side of the river the only openings known to have been made for magnetite were the Conklin, Mine Hill, Rattlesnake, Boyer or Kohl, and Nicholas mines. The only ones of any importance were the Mine Hill and Rattlesnake, which, together with

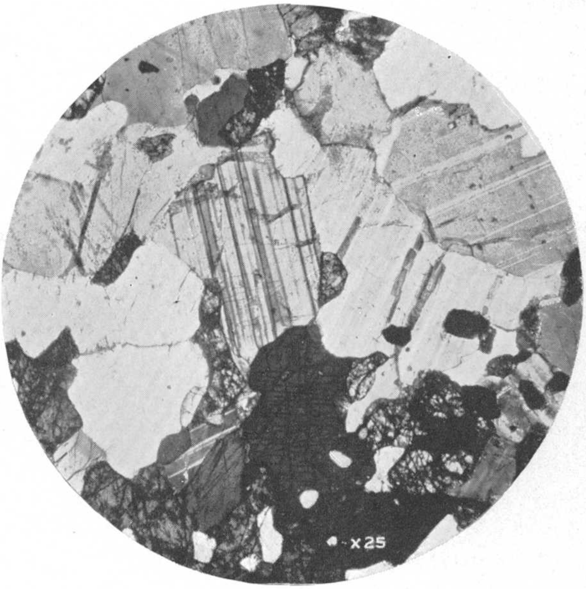
POLISHED SLAB OF GNEISS, SHOWING INJECTION OF DARK SCHIST (PICKERING GNEISS) BY GRANITIC MATERIAL.

Washington mine, near Oxford, N. J. The light parallel streaks on the left are layers of normal Byram granite gneiss. The large light area to the right is a pegmatitic phase of Byram gneiss in which are many very thin streaks of the black schist.



A. PHOTOMICROGRAPH OF LOSEE DIORITE GNEISS

Near Mountainville, Tewkesbury County, N. J. Shows plagioclase, quartz, brown-green amphibole (dark), pink-green pyroxene (gray), and a few small grains of magnetite and apatite. Polarized light.



B. PHOTOMICROGRAPH OF BYRAM GRANITE GNEISS.

Road half a mile north of Williams mine, Vernon Township, Sussex County, N. J. The main mass is microcline-microperthite; the uniform white and gray areas represent quartz; and the triangular area in the center and the irregular one at the bottom are pyroxene. Polarized light.

a few other unnamed pits, constituted the well-known Durham mine, but the product was mainly hematite. This mine is now abandoned.

OCCURRENCE OF THE ORE

The magnetite deposits occur (1) as richly magnetiferous pegmatites, (2) as layers of lenses in the Franklin limestone, and (3) as interleaved layers in the Byram and Losee gneisses and the schists of the Pickering gneiss.

MAGNETIFEROUS PEGMATITE

The magnetiferous pegmatite is merely pegmatite that contains sufficient magnetite to warrant its consideration as a source of iron. The magnetite occurs disseminated through the rock irregularly, both as inclusions within the other rock constituents and as interstitial masses between them. The rock is therefore very unequal in quality as an ore. In some places it may be rich enough in iron to warrant working, but at short distances from these places it is likely to be rather lean. Moreover, because of its granitic character and the consequent necessity of breaking it into small pieces, it is expensive to cobb. For these reasons it is not a satisfactory ore to work, and consequently all the mines that were situated on pegmatite deposits were abandoned many years ago.

ORE BODIES IN THE GNEISSES AND SCHISTS

Ore veins.—The ore bodies associated with the gneisses and schists are by far the most valuable. Practically all the most productive mines were situated upon them.

The ore-bearing rocks have the same general relations to the surrounding rocks as the layers of Pochuck gabbro gneiss have to the light-colored gneisses and schists. They constitute thin layers striking and dipping with the associated schistose rocks and wedging out at their ends where not terminated by faults. In some places the contacts with the adjacent gneisses and schists are sharp, but in many places the ore layers and the country rock grade imperceptibly into each other. On the surface the trace of the magnetiferous layers can be followed for considerable distances by their weathering products, which extend across country in straight lines as rusty-red streaks made up of hornblende, biotite, quartz, and limonite. These layers, which are known as the ore "veins," contain rich and lean portions; the rich portions are the ore bodies. Where not deeply weathered the veins differ very little from the ordinary Pochuck gabbro gneiss, except that they contain a greater proportion of magnetite.

The ore-bearing layers range in thickness from a small fraction of an inch to 50 feet or more, but the average thickness is from 4 to 20 feet. They occur in narrow belts or ranges separated by wider belts of barren rock. The width of the ore ranges is rarely more than 2 miles and is usually less than half a mile. The productive portions of some belts attain lengths of 30 miles or more, but more commonly than otherwise they are less than 1 mile long. These ranges may be regarded as mineralized zones. Within the ranges there may be a single ore-bearing layer or vein, or there may be several parallel veins of large size and numerous small ones so thin as to be unworkable.

The developed portions of the veins vary greatly in length. Some are extremely short, being limited to the length of a single ore body. Others are 300 to 400 feet long and may contain a succession of several ore bodies. The vein at the Washington mine has been traced by its magnetism for a distance of 4,000 feet and has been developed through a length of at least 1,700 feet.

Shapes of the ore bodies.—Practically all the richer ore bodies are distinctly pod-shaped lenses, with their longitudinal planes parallel to the dip of the foliation in the neighboring gneisses and their longer axes conformable with the pitch of the rock structure (fig. 3). Usually several of these lenses lie one above another in the same plane, all pitching and dipping in the same direction. The pods are known as shoots, and the comparatively barren rock between them as pinches. The succession of shoots and pinches in their horizontal direction constitute the vein.

The pinches, though poor in ore, are not entirely barren. In some veins the walls close in, reducing the width of the vein and its contained ore bodies to a few feet or even a few inches. More commonly, however, the space between the shoots is occupied by rock, which is usually different from the country rock. In some places it is a pegmatite full of magnetite; in others it is a mass of coarse hornblende crystals cut by tiny veinlets of ore running parallel with the general direction of the gneiss and connecting the shoots with one another. In a few places the pinches are so narrow that the vein is reduced to a few or many very narrow stringers of magnetite, traversing the country rock and connecting the ore shoots with one another.

The shoots, moreover, are not uniform throughout. In many places a slab of rock—a horse—divides the ore mass into parts that may remain separate for long distances. In other places the rock slab may project into the ore body from beneath, or from above, separating it into parts that may have the appearance of limbs of folds, as at the Hurdtown mine, in the Raritan quadrangle.

Most of the veins consist of a single succession of shoots and pinches. In a few, however, double shoots occur in parallel position on the same vein, and several veins may run parallel for long distances and so close together that the shoots in two veins are worked from the same mine shaft (pl. 4). Again, a series of parallel veins may exist in a strip of country and be separated from another similar series of parallel veins by a comparatively wide expanse of country without ore veins. Such a mineralized zone extends from Hacklebarney to Wharton.

No definite rule as to the distribution of the ore-bearing layers can be formulated. So far as is known structural features do not deter-

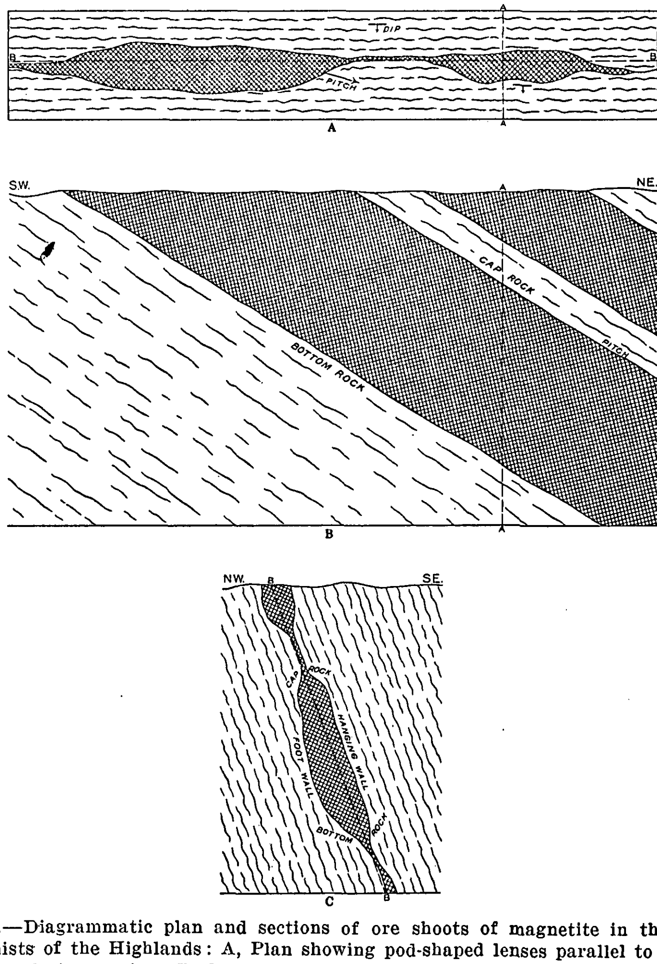


FIGURE 3.—Diagrammatic plan and sections of ore shoots of magnetite in the gneisses and schists of the Highlands: A, Plan showing pod-shaped lenses parallel to the strike of the enclosing gneiss; B, longitudinal section in the plane of the dip of the ore shoot along the line B—B; C, vertical cross section along the line A—A.

mine their positions, nor are they limited to any one kind of rock. Moreover, no faults that have been recognized extend along their length, nor do the ore-bearing beds occur in crush zones. The rocks associated with the ore veins exhibit no more granulation than similar rocks between the belts of veins.

Cap and bottom rocks are supposed to terminate the horizontal extension of the vein in the two directions, so that beyond the vein on its strike no continuation of the shoots is to be expected. In other portions of the Highlands this notion has not been shown to be well founded, for by following the small streaks of ore that extend from their supposed ends the veins are often found to open up and to contain ore. Wherever the ore bodies have appeared to terminate suddenly, this has been due to cross faults which have displaced the vein to such a distance that persistent search has failed to discover its continuation.

In the Delaware Water Gap and Easton quadrangles the development of the mines has been so slight that very little information is available as to the underground relations of ore and rock, but there is no reason to believe that the conditions in this district are any different from those in other portions of the Highlands.

Character and mineral composition of the ore.—The vein matter of all the mines is practically of the same character, though it differs in the proportions of the minerals present. It consists of an intimate mixture of magnetite, hornblende, pyroxene, quartz, feldspars, biotite, apatite, sphene, and pyrite. Hornblende, pyroxene, and apatite are the most persistent of the components aside from magnetite, and quartz is common. Apatite is present as small green, gray, or brown granules, at some places in large quantity and at others only in minute traces.

The minerals associated with the magnetite in the ore bodies are usually those found also in the rock surrounding the ore. The principal components of the ores in the gneisses in addition to magnetite are hornblende, pyroxene, feldspars, quartz, apatite, sphene, pyrrhotite, and pyrite. The proportion of these minerals in different parts of the veins varies, in many places becoming so great and the mixture so lean that it is no longer available as a commercial ore. Furthermore, the apatite varies widely independently of the other components. In some ores it is so sparse that the ore may be within the bessemer limits. In other ores its proportion is so large that the material has not been used as a source of iron but is so rich in phorphorus as to have attracted attention as a source of phosphoric acid.

Pyrite is almost universally present, but in much of the ore only sparingly. Some of it is in the form of veinlets, which were formed after the magnetite. Calcite in thin layers along fractures is also locally present as a late introduction.

In addition to the minerals mentioned above, which are present in most of the ores, some of them contain also biotite, chlorite, sillimanite, garnet, epidote, fluorite, molybdenite, and other less common minerals.

From the brief description of the ore veins given above it is evident that those in the gneisses and schists do not differ materially in character from the bands of Pochuck gabbro gneiss or from some of the magnetiferous pegmatites. They strike and dip with the surrounding rocks, have the same pitch, and end like the Pochuck layers.[43]

ORE BODIES IN THE FRANKLIN LIMESTONE

The ore found in the Franklin limestone occurs in a variety of forms. In some places, as at the Ahles mine and the other mines in the Pequest area, it constitutes a comparatively thick layer of uniform width running for a long distance without interruption. In other places the ore is apparently in an irregular-shaped mass that is so involved with black dioritic rocks that its outline is impossible to decipher with certainty. Moreover, the limestone is impregnated with magnetite crystals for considerable distances beyond the ore body proper. Consequently the ore body, or that portion of it which is considered to be rich enough to work, grades into the surrounding limestone by almost imperceptible transitions. This is probably the mode of occurrence at the Raub mine, but here in addition various sulphides are present.

A third type of ore body in the Franklin limestone is that represented by the Sulphur Hill mine, in the Franklin Furnace quadrangle, where the ore is partly in limestone and partly in gneiss.

Most of the ores associated with the limestones are not very different from those in the gneisses. The insoluble constituents consist mainly of quartz and hornblende or pyroxene, and in the Sulphur Hill mine, in the Franklin Furnace quadrangle, also willemite. The soluble components are magnetite, calcite, pyrite, pyrrohotite, and other sulphides, among them chalcopyrite, galena, and sphalerite, and also sphene and apatite. In the Ahles ore there are no sulphides except those of iron, but a large quantity of pyrolusite is present in the form of little nodules scattered through the limonite. The magnetite is nontitaniferous and thus appears to differ from that in the ores associated with the gneisses. In many of the limestone ores there is also present considerable garnet, and in some of them some chondrodite and serpentine—these three minerals being common constituents of the metamorphosed limestone with which the ore bodies are associated.

CHEMICAL COMPOSITION OF THE ORE

The chemical composition of the ores varies, of course, with the manner of preparing them for market. The ore as it is obtained from some of the mines is nearly rich enough to be a commercial

[34] For a more detailed description of the magnetite ores in the pre-Cambrian rocks of the Highland belt see New Jersey State Geologist Final Rept., vol. 7, pp. 89–116, 1910.

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product. That of most mines, however, must be washed or cobbed before it becomes merchantable. All the ores contain the same constituents, but in very different proportions. Those from the veins in the gneisses usually contain too high a percentage of P_2O_5 to be of bessemer grade. Titanium is also usually high, but manganese and water are low. On the other hand, the ores in the limestone usually contain but little phosphorus and titanium. Manganese and water, however, are usually high. Determinations of manganese in ores in the limestone range between 0.25 and 7.13 percent and of titanium dioxide from 0.0 to 0.19 percent. The corresponding figures for samples of ores known to have come from the gneisses with two exceptions are between 0.04 and 6.3 percent and between 0.0 and 9.18 percent.

Two analyses of ores exhibiting some of these characteristics are as follows:

Analyses of magnetite ores

	1	2		1	2
Fe	47.65	60.431	CaO	1.26	1.70
Mn	4.35	.02	MgO	1.64	.47
SiO_2	15.705	7.800	S	.038	.042
Al_2O_3	1.35	1.292	P	.092	.492
			H_2O	undet.	

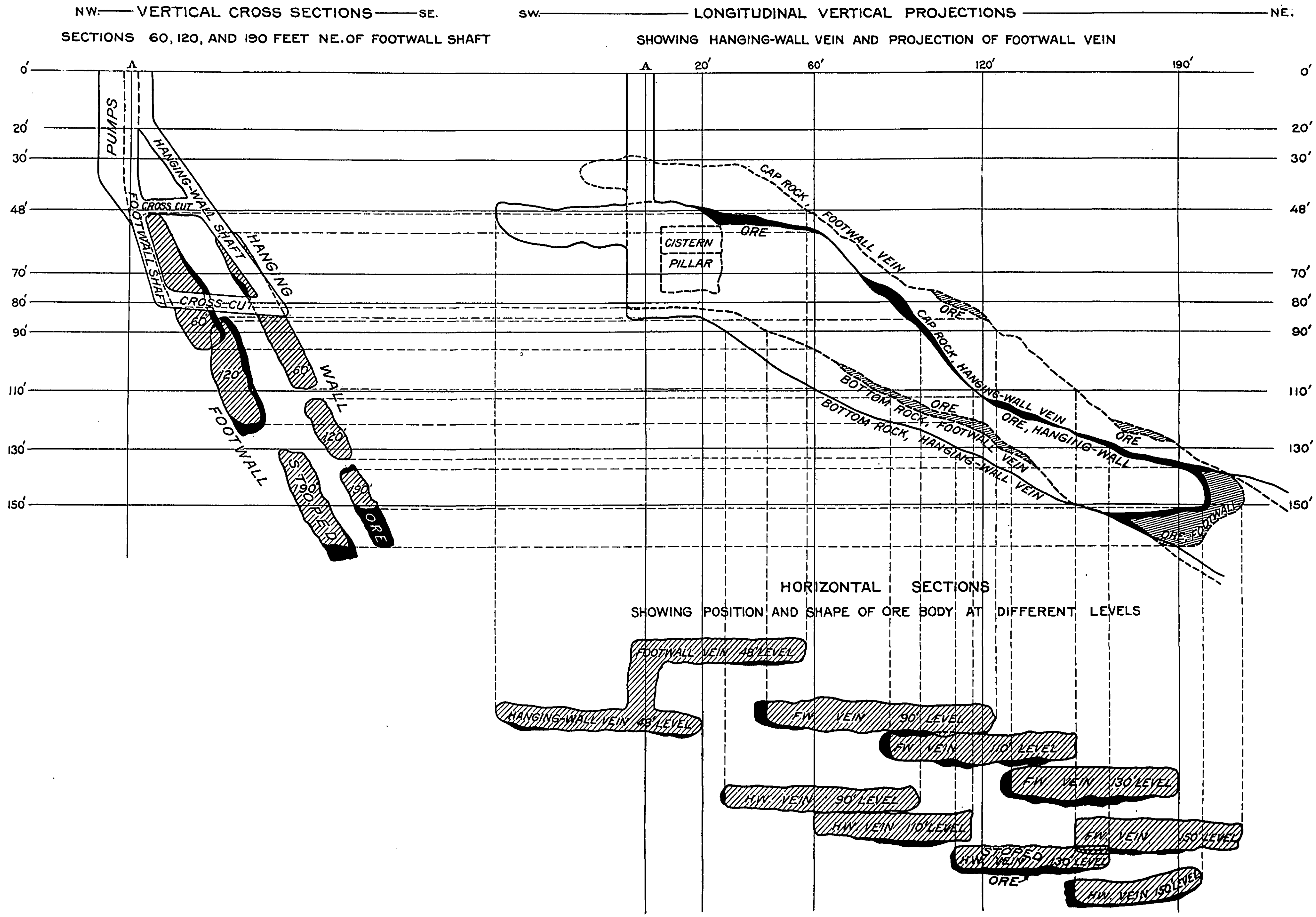
1. Average sample of ore raised from Ahles mine in 1902. Ore dried at 212°. Water content is between 10 and 12 percent. New Jersey State Geologist Ann. Rept. for 1904, p. 295.
2. Average sample from Elizabeth mine, in Raritan quadrangle. Analysis furnished by Empire Steel & Iron Co., except figures for Mn, which are taken from an analysis by R. B. Gage, of the New Jersey Geol. Survey. Iron mines and mining in New Jersey: New Jersey State Geologist Final Rept., vol. 7. p. 416, 1910.

ORIGIN OF THE ORE

The ore veins in the gneisses and schists are not essentially different from layers of Pochuck gabbro gneiss, except that they contain more magnetite, or from some of the magnetiferous pegmatites. The magnetite may be disseminated uniformly through the vein rock or it may occur in tiny veinlets running approximately parallel to its structure. Where it occurs in such veinlets the rock is also more magnetiferous than elsewhere.

Where the ore is rich—that is, where it occurs in definite shoots—it contains more or less of the minerals recognized as characteristic components of the gneisses—namely, hornblende, pyroxene, quartz, plagioclase, and apatite. The calcite and pyrite, where they have been seen, are later introductions in the form of veins cutting through the ore.

In a few places the magnetite has been observed in irregular masses within the Losee gneiss and having such relations to the surrounding rock as to suggest that it is in a basic secretion analogous to the secretions of the titaniferous magnetite in certain gabbros. In other places the entire rock within limited areas, whether Byram or Losee, is so uniformly besprinkled with magnetite grains as to suggest that it is impregnated with the iron oxide.



SECTIONS THROUGH THE ORE BODIES OF THE WELDON MINE.

From a consideration of the above facts, it is concluded that the ores associated with the gneisses and schists are of magmatic origin—that is, the source of their material is thought to be the deep-seated molten magmas, which upon being intruded into the overlying rocks solidified as the various gneisses now constituting the principal rocks of the Highland ridges. After the partial cooling of the gneisses they were in turn intruded by ferruginous portions of the same magma that gave them birth, producing pegmatites and hornblende-augite masses, and these intrusions were later enriched by iron-bearing solutions or vapors originating in the same subterranean source. In their transit to the surface these solutions or vapors deposited additional magnetite in the intruded ferruginous rocks, perhaps replacing some of the earlier minerals, and made the ore lenses that now constitute the ore bodies. The tiny veinlets of magnetite that are so common in the ore veins indicate that the ore-bearing solutions were of low viscosity.

The ores in the limestone present many of the same features as those in the gneisses. The shoot structure is perhaps not so well defined, nor is there in most places so distinct a vein. The conditions are in many places complicated by the presence of intrusive basic rocks, which have evidently metamorphosed the limestones and brought about an intermingling of metamorphic minerals with the normal components of the ores.

The character of the ore in the limestone differs from that in the gneisses and schists only so far as it is affected by the differences in the character of the rock by which it is enclosed. The black hornblende and pyroxene that are characteristic associates of the ores in the siliceous Pickering rocks are rare in the ores in the limestone, in which calcite is the prominent gangue material. On the other hand, colorless or light-green pyroxene, garnet, micas, and some other silicates that may have been produced by metamorphism of the limestone are frequently found in the ores in the limestone. In some places much limonite is intermingled with the magnetite, and this mixture contains nodules of pyrolusite. Most of the ore bodies in the limestone include shoots that are similar to those in the gneisses, but at the Ahles mine the mixed magnetite and limonite form a dikelike mass with straight walls extending for a considerable distance without the shoot and pinch structure that is so noticeable in the mines in the gneiss. The absence of this structure may be due to the fact that development of the ore body had not proceeded far enough to disclose it—that the mining was on a single shoot of great size. The ore of this mine contains a few decomposed feldspar crystals, now changed to soft kaolin, and a few doubly terminated crystals of quartz. There are also large nodules of ferruginous chert enclosing pockets of limonite and crystals of magnetite.

The magnetite bodies in the limestone are probably the result of the two processes already outlined in connection with the ores in the gneisses and schists. The magnetite was probably introduced into the limestone by intrusion of aqueo-igneous material emanating from deep-seated sources, and during this process the limestones near the ores were silicified. The acid portions of the magma reacted upon the limestones, with the formation of lime silicates, and consequently the ore did not take the form of pegmatite as it did in the gneisses, although here and there, as has already been related, a few feldspar crystals and grains of quartz scattered through the ore bodies give evidence of the siliceous character of the ore-depositing agency. The hot solution that followed the aqueo-igneous intrusions added more iron and enriched the ore bodies partly by depositing additional magnetite in contraction cracks in the limestone and partly by replacing the calcite adjacent to the ore bodies. At the Ahles mine (32) and the other mines in its vicinity the magnetite in the ore body is embedded in limonite in which are also little nodules of pyrolusite, but at most of the mines in the limestone in other parts of the Highlands magnetite, calcite, and the various silicates associated with these minerals in the ore vein form a compact mass in which neither limonite nor pyrolusite can be detected. The form in which the manganese was originally present in these ores is unknown. The analysis of the magnetite separated from the ore of the Ahles mine (p. 60) shows that it is not in that constituent. However, as magnetite is present in noticeable quantity in all the ores in the limestone, it is inferred that this element may have been disseminated in the rock before it was invaded by the intrusions from below.

At the Ahles mine and some other mines in the limestone the mixture of limonite and pyrolusite is thought to be the result of replacement of the limestone that otherwise would have appeared as the gangue of the ore. The iron and manganese were presumably introduced by the ascending ferruginous solutions and later concentrated through oxidation and transfer by downward-percolating meteoric water, as the surface ores are all richer in manganese than those deeper down, and the soft portions of the ores are richer than the more compact portions.

A fuller discussion of the reasons for the conclusion as to the origin of the magnetite ores in the Highlands is given in other publications.[44]

[44] U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), pp. 10, 23–24, 1914. Iron mines and mining in New Jersey: New Jersey State Geologist Final Rept., vol. 7, pp. 147–156, 1910.

OTHER VIEWS ON THE ORIGIN OF THE ORE

Nason[45] has suggested that some of the magnetite deposits in the Adirondacks, which are almost identical in character and associations with those in the gneisses in the Highlands, are of sedimentary origin. He is inclined to this view because his observations, based largely on drill records, seem to indicate that the ores occur mainly if not exclusively in a gray gneiss which in some places is interleaved with limestones and quartzites of Grenville age and which, therefore, is an integral part of the Grenville and is thus sedimentary.[46] Unfortunately, however, no petrographic study of the "gray gneiss" was made, and it is, therefore, impossible to correlate this gneiss with any of the gneisses in the Highlands; but, if it is similar to Nason's Mount Hope type in New Jersey,[47] it is a part of the rock mapped as the Losee gneiss in the folios of the United States Geological Survey and is believed to be an intrusive.

Moreover, Nason observed that "the iron-ore beds and their gray gneisses are affected as a unit. If the ore is rolled the gray gneiss is likewise affected; if the ore is faulted, the gray gneiss is likewise faulted; in short, the ore and gray gneiss, so far as intrusives are concerned, were pre-existing." The structural features of the gray gneiss he found to be "in conformity, in general, with the great orographic structure of the Allegheny Mountain system," and their contained ore bodies to be "in every way conformable to these gray-gneiss structural lines. If the foliations of the gneisses are disturbed, the ore bodies are equally disturbed. In rolls, faults, warpings, if the enclosing gneisses are distorted, the ore bodies are equally distorted."[48]

The logs of diamond-drill holes suggested to Nason "that the regularity of these structural lines in the gray-gneiss series can be accounted for in no other way than by that of sedimentary origin. * * * It is also possible to state without contradiction that the structural lines of the gray gneisses and their associated gneisses are in perfect conformity with the structural lines of the Grenville white limestone,"[49] the sedimentary origin of which cannot be doubted, and that the formation of these structural lines preceded the intrusion of certain eruptives.

Nearly all the features of the magnetites and gray gneisses of the Adirondacks have their counterparts in the magnetites and associated gneisses in the Highlands, but in the view of the writer they are

[45] Nason, F. L., Sedimentary phases of the Adirondack magnetic iron ores: Econ. Geology, vol. 17, pp. 633–654, 1922.
[46] Idem, p. 644.
[47] Nason, F. L., in New Jersey Geol. Survey Ann. Rept. for 1889, p. 30, 1889.
[48] Nason, F. L., op. cit. (Econ. Geology), p. 647.
[49] Idem, p. 648.

just as reasonably explained on the inference that the gneisses associated with the ores are igneous as on the assumption that they are sedimentary. Moreover, the petrographic study of the gneisses and their chemical composition seem to confirm this view. The intrusions were controlled by the structure in a preexisting series of interleaved sedimentary and igneous rocks (partly Nason's Grenville series), and consequently the entire set of rocks is necessarily conformable. In the Highlands many of the lean ores are magnetiferous pegmatites that cannot possibly be regarded as sedimentary, and these are conformable with the other rocks in the district in the same way as the gneisses.

Nason's argument that because the magnetites in the gabbros and syenites of the Adirondacks are titaniferous and the ores of the "gray gneisses" nontitaniferous, therefore the latter are probably sedimentary, is not applicable to the Highland ores, for the magnetites in the gneisses of the southern area contain titanium in amounts ranging from a trace to 7 percent.

Miller[50] in discussing Nason's article calls attention to the fact that even in the Adirondacks there are few ores that do not contain titanium and quotes Newland[51] as follows: "The term 'nontitaniferous,' it may be noted, is hardly an accurate one to apply to any of the Adirondack magnetites, since titanium has been shown to be almost universal in these ores."

Miller differs from Nason in not accepting the generalization that the ores are everywhere associated with the "gray gneiss." On the contrary, he states that as the result of wide field work he believes that

> the ore is directly associated with a more or less intimate combination of granite (or syenite) and an older gabbro (or metagabbro), the granite, or pegmatitic phases of it, having intruded and more or less injected the gabbro, giving rise to a crude banded effect, parallel with the magmatic flow-structure foliation. * * * Nason's logs of drill holes * * * are excellent examples of just such combinations of rocks, in which his "gray gneiss" bands are, in my judgment merely zones or belts of magmatic origin closely associated with bands of an older more or less injected or assimilated gabbro. In this connection it should be stated that there is also probably gabbro of later age than the syenite granite series, * * * and Nason may be confusing these two, as I gather from reading his paper. His "gray gneiss" seems to be identical with the great body of what I have called the Lyon Mountain granite, which encloses the ore bodies at Lyon Mountain. This country rock at Lyon Mountain is certainly of igneous origin, as proved not only by its more or less intimate penetration of an older dark gneiss (metagabbro), but also by its noteworthy development of pegmatitic and silexitic facies.[52]

[50] Miller, W. J., Nason on "The sedimentary phases of the Adirondack magnetic iron ores:" Econ. Geology, vol. 17, pp. 709–713, 1922.
[51] Newland, D. H., New York State Mus. Bull. 119, p. 23, 1908.
[52] Miller, W. J., op. cit., pp. 710–711.

In these words Miller describes relations existing between the gray gneiss, the gabbro, and the ores in the Adirondacks that are identical with those existing between the Losee and Byram gneisses, the Pickering gneiss, and the Pochuck gabbro gneiss, and the ores in the Highlands of New Jersey.

Further he writes:[53]

> The facts that the ore bodies often show considerable linear extent and have "foliation planes no less strongly developed than those in the containing rocks and these foliations are exactly conformable to those of the rock host," are, according to Nason, strong evidence for the sedimentary origin of the ore. In my original paper I interpret the parallelism of strike and dip of the ore zones and their foliation as due to magmatic flowage when both the syenite-granite (country rock) and ore-zone magmas were subjected to moderate pressure during the process of intrusion and crystallization. Under such conditions, is it any more surprising that the ore zones of magmatic origin often show considerable linear extent than that, commonly throughout the Adirondacks, long belts or zones of the syenite-granite series, different in composition from the general rock, developed under magmatic conditions?

In other words, Miller's explanation for the parallelism of the ore zones with the structure of the enclosing rocks is identical with that offered for the similar parallelism of ore and country rock in the Highlands. (See p. 55.)

With reference to the source of the iron in the ore deposits, Miller suggests[54] that it "may have been derived from the old iron-rich gneiss by magmatic (pegmatitic) solutions." This is the same source that has been suggested for the ores of the Highlands, except that, in addition, some of the ore bodies in the Highland district are believed to be injected portions of a magma that had been segregated or differentiated from the parent magma. At present the writer is inclined to believe that the greater part of the nontitaniferous ores of the Highlands were furnished by pegmatitic solutions and that these deposits were later enriched by emanations that formed the small veins of nearly pure magnetite which cut through the pegmatitic deposits and the pinches between them and connect the lenses in the same vein. This view is reinforced by the study of the nontitaniferous ores of the southern Appalachians[55] in which the magnetite is believed to have been furnished by ferriferous liquids that gave rise to magnetite-pyroxene pegmatites and a little later to magnetite veins.[56]

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[53] Miller, W. J., op. cit., pp. 712–713.

[54] Idem, p. 713.

[55] Bayley, W. S., General features of the magnetite ores of western North Carolina and eastern Tennessee: U. S. Geol. Survey Bull. 735, p. 227, 1922.

[56] For a brief discussion of the physico-chemical factors controlling vein formation of this kind see Ross, C. S., Econ. Geology, vol. 23, pp. 864–886, 1928.

COMPARISON WITH THE MAGNETITE ORES OF THE SOUTHERN APPALACHIANS

The magnetite ores in the pre-Cambrian limestone and gneisses of the Highland belt in New Jersey and Pennsylvania bear a remarkably close similarity to the nontitaniferous magnetites in the mountain districts of North Carolina and Tennessee.[57] In both districts the character of the ores in the gneisses is the same and their relations to the surrounding rocks are similar. Ores in limestone are rare in the southern district, but those present are like those of the north in differing from the ores in the gneisses in their larger content of manganese and smaller content of titanium.

In origin also the ores in the two districts are believed to be alike. The theory of the origin of the northern ores has already been outlined. In the southern area the relations of ore and rock suggest that the ores were formed by an intrusion that took place before the general deformation of the mountain region was concluded. The intrusive mass was apparently a magnetitic pyroxene pegmatite, followed later by one of pyroxene magnetite and finally by one of magnetite. Thus the succession of events that produced the ores is believed to have been in general the same in the two districts. In both districts intrusions of less silicious ferriferous material, which formed pyroxene pegmatites and magnetites, followed those of more siliceous material, which formed more siliceous pegmatites. In both districts also the intrusions were controlled in their arrangement by a series of preexisting schistose rocks into which they were forced and later were brought into more complete conformity with them by the movements that resulted in the folding of the two districts during Paleozoic time; consequently, the ore veins now appear as layers interleaved with the country rocks.

MAGNETITE MINES

Although formerly there were almost a dozen large iron mines in the pre-Cambrian rocks of the Easton and Delaware Water Gap quadrangles, most of them were closed down before 1910. Only one—the Washington mine—was being operated in 1923; then after a period of idleness shipments were resumed in 1931 and have continued at intervals since. Most of the mines were in the Pequest area of the Franklin limestone; but the two most productive—the Washington mine, at Oxford, N. J., and the Durham mine, near Durham,

[57] Bayley, W. S., General features of the magnetite ores of western North Carolina and eastern Tennessee: U. S. Geol. Survey Bull. 735, pp. 225–227, 248–249, 1922; The magnetic iron ores of east Tennessee and western North Carolina: Tennessee Div. Geology Bull. 29, 252 pp., 1923 (published also as North Carolina Geol. and Econ. Survey Bull. 32, 252 pp., 1923).

Pa.—were in gneiss or schist. The Durham mine, however, is reported to have produced more hematite than magnetite, but as the geologic relations of its ore to the country rock are thought to be the same as the relations of the ore to the gneiss in the magnetite mines, it is grouped with them.

MINES IN THE FRANKLIN LIMESTONE

Openings in the limestone.—The principal mine openings [58] in the Franklin limestone were the Queen (31), Little (29), Riddle (30), Raub (28), Ahles (32), and Osmun (33), all of which were in the Pequest area, near Buttzville, N. J., and all of which at one time or another were shipping mines. In addition there was an opening known as the Schuler mine (22) on the west slope of Scotts Mountain, about three-quarters of a mile northeast of Roxburg. It was never more than an exploration.

As all these mines were described in a New Jersey report, published in 1910,[59] and there has been no further development of any of them since that time, it is unnecessary to describe them again in detail. At nearly all the mines the ore was the same. Near the surface it was a mixture of ocherous limonite, crystallized magnetite, and small nodules of pyrolusite. At greater depth it was a compact mass of calcite and magnetite in small veins and irregular lumps. When piled on the dumps it rapidly disintegrated, the calcite dissolving and leaving a soft mass of limonite and pyrolusite enclosing the hard lumps of magnetite. This was washed, yielding a hard and a soft ore, of which usually only the hard ore was saved. The difference in composition between the two parts is shown by the analyses of the magnetite and limonite separated from the ore of the Ahles mine, which in the sample analyzed consisted of 63 percent of "hard" ore, 15 percent of "soft" ore, and 22 percent of a mixture of the two.

Analyses of "hard" and "soft" portions separated from ore of Ahles mine

[Analyst, E. C. Sullivan, U. S. Geol. Survey]

	Hard ore	Soft ore		Hard ore	Soft ore
SiO_2	10.60	16.96	H_2O-	1.36	5.13
Al_2O_3	1.85	4.06	H_2O+	2.55	7.16
Fe_2O_3	7.52	50.91	TiO_2	Tr.	Tr.
Fe_3O_4	70.24	----------	P_2O_5	Tr.	.33
MgO	.62	1.54	MnO_2	4.19	11.28
CaO	.29	.66	BaO	.41	1.44
Na_2O	} .12	.08	SO_3	.06	.20
K_2O		.29			
				99.81	100.04

[58] Numbers in parentheses following names of mines correspond to those showing their positions on the geologic map (pl. 5).

[59] Bayley, W. S., Iron mines and mining: New Jersey Geol. Survey Final Rept., vol. 7, 1910.

In many of the lumps on the waste dump heaps the relations of the ore to the rock were seen to advantage. Large fragments of compact ore were covered with a layer of limonite; others were weathered in ridges, the ferruginous portions forming the higher parts; others were masses of crumbly and often gritty limonite filled with little nodules of pyrolusite and crystals and larger irregular masses of magnetite. On broken surfaces of the fresh fragments little veins of magnetite could be seen cutting through the limestone parallel to its structure. In all specimens examined the limestone has assumed a blue tinge and was decidedly darker than the ordinary white limestone in ledges at a distance from visible ore deposits. The pyrolusite and limonite could not be detected in the unweathered specimens. They were developed only after the limestone had been attacked by the atmosphere.

Ahles mine.—At the Ahles mine, later known as the Pequest mine (32), the relations of the ore to the country rocks were somewhat different from those in the other mines in the limestone area. The Ahles mine was on the east side of the road from Oxford to Bridgeville, almost a mile northwest of Oxford and a short distance north of a ridge of Byram gneiss. There were three shafts and a slope, distributed along a line about 1,800 feet long and about 200 feet northeast of the outcrop of the ore vein, which is a continuous layer of ore from 20 to 40 feet thick, striking N. 60°–70° W. and dipping 80° SW. (fig. 4). On the upper levels the ore was 40 feet wide as far as a horse of pegmatite, which was 2.5 to 30 feet thick. South of the pegmatite was a short ore lens from 5 to 30 feet thick, and south of this a decomposed siliceous rock that passed gradually into a banded gneiss, resembling the Byram gneiss on the hill farther south. On the footwall of the main ore body is a finely banded gray gneissic rock, the less siliceous layers of which are composed of colorless pyroxene, calcite, a little biotite, and some serpentinized chondrodite. The more siliceous layers consist mainly of oligoclase, microcline, green augite, green hornblende, and calcite. The rock containing serpentinized chondrodite is probably a metamorphosed phase of the Franklin limestone, and the feldspathic rock is one of the members of the Pickering gneiss, corresponding to the rocks in the Delaware River. (See p. 26.) The ore was similar to that in the other mines. It was a mixture of soft brown limonite, nodules of pyrolusite, and crystals and crystal groups of magnetite, the whole enclosing boulders of limestone partly replaced by limonite. There were also present in the ore great masses of chert and cherty limonite, some of which were gashed and jointed, with the surfaces of the cracks coated with cherty quartz. The relation of the chert to the rest of the ore was not learned, but it was apparently found only in the upper portion of the ore body.

The mine was first opened in 1901, was operated continuously for nearly 15 years, and produced about 300,000 tons of ore. It was closed not for lack of ore but because of the high cost of mining and the expense of preparing the crude ore for market. During the mine's operation many tons of washed ore was stocked and the soft ore was sold for paint. In 1923 the stock pile was being shipped at the rate of about 300 tons daily by the Edison quarry railroad to the Eastern Steel Co. at Pottstown.

The approximate analysis of this ore was as follows:[60]

Partial analysis of ore from stock pile of Ahles mine, New Jersey

Fe	44.00	SiO_2	20.98
Mn	3.88	Al_2O_3	1.31
P	.095	CaO	.71
Moisture	20.50	MgO	1.27

Production of the mines in limestone.—The total amount of ore shipped from all the mines in the Pequest area was probably not

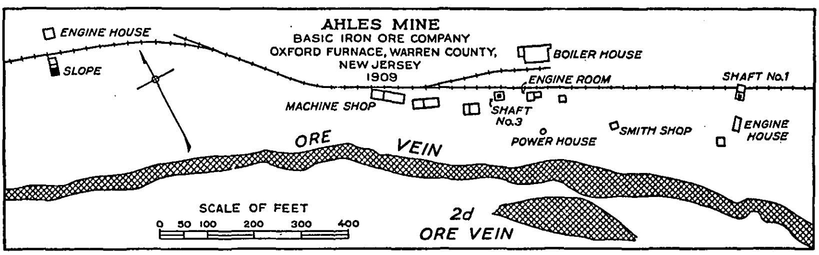

FIGURE 4.—Map of surface at Ahles mine. Reproduced from New Jersey Geological Survey Final Report (vol. 7, fig. 13, 1910).

more than 500,000 tons. The abandonment of the mines was not due to exhaustion of the deposits but to the increasing cost of mining owing to constantly increasing depth. The veins are comparatively narrow and dip steeply, so that the depth of mining increases rapidly as the ore is removed. Moreover, much of the material raised was wasted in the washing process, and that saved would not bear the cost of preparation, except when the price of ore was comparatively high. As all the mines were shallow and bottomed in ore when they were abandoned, it is inferred that there is a large reserve in the ground awaiting a time when it can be mined with profit.

MINES IN THE GNEISSES AND SCHISTS

The only mine that was operating on the deposits in gneiss during 1923 was the Washington mine (21), at the village of Oxford. Formerly the Harrison, Swayze (15), and West End (14) mines in

[60] Private letter June 24, 1924, from S. O. Hobart, general manager of furnaces of the Eastern Steel Co., Pottstown, Pa.

New Jersey and the Durham mine (3) in Pennsylvania were large producers, but they have not been operated since 1910. The Harrison deposit, however, is now being worked through the Washington mine shaft, and a little exploratory work has been done at the Swayze and West End mines. The Durham mine was an almost continuous producer for more than a century, but it was closed in 1906.

Washington mine.—The Washington mine (21) is one of several openings in a series of veins south and west of the village of Oxford that have been worked for nearly 200 years. Only the Harrison and Washington mines are in the Easton quadrangle. The other openings of the Oxford group are in the Hackettstown quadrangle, which forms the northwest quarter of the Raritan 30-minute quadrangle.[61] The Harrison and Washington mines are on the westernmost vein of the series, which consists of two seams of ore separated by gneiss. The vein was traced by W. H. Scranton for a distance of 4,000 feet by magnetic methods. Its average thickness is reported to be 11 feet, its strike about N. 25° W., and its dip 45° SW. Shafts have been sunk on it at intervals, each new one south of the older ones, the present operating shaft being the southernmost. From this shaft shipments began about May 1, 1923, at the rate of about 12,000 tons monthly, and continued until October, when the mine was temporarily closed.

At the shaft the deposit is said to be about 20 feet wide in a vein 60 feet wide that dips 37°–70° E. In the footwall and in the vein there is much pegmatite. The ore is crushed, screened, cobbed by magnets, and then roasted in a battery of 16 roasters to remove the sulphur, which has been a constant accompaniment of the ore throughout the vein. The result of the screening is separation into two parts, one consisting of 65 percent of 1½-inch fragments and the other of 35 percent of fine materials. The fines are passed over Ball-Norton separators, which increase their metallic content about 2 percent. The larger fraction is then roasted in Jgiers kilns and the finer material is desulphurized in a Wedge gas kiln. Formerly the entire product was passed through the Jgiers kilns, but the result was not so good as when the two fractions were treated separately, as the sulphur could not be reduced below 0.80 percent.[62]

The ore before roasting contains about 58 percent of metallic iron and 2.75 percent of sulphur. After roasting its composition is as follows:

[61] See U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 25, 1914.
[62] Letter June 23, 1924, from Leonard Peckitt, president Replogle Steel Co., New York.

Analysis of roasted ore from Washington mine, Oxford, N. J.

[Courtesy of Replogle Steel Co.]

Fe	60.00	Cu	0.01
Mn	.10	SiO_2	7.00
S	.50	Al_2O_3	2.75
P	.45	CaO	2.50
Ti	.14	MgO	1.25
V	.03		

Durham mine.[63]—The Durham mine (3) is at Durham Furnace, near Monroe, on the Delaware River about 8 miles south of Easton, Pa. It is one of the oldest mines in the United States and was formerly one of the most productive. It was first opened in 1698, and in 1727 it furnished ore to a furnace built near the village of Durham. During the War of the Revolution this furnace supplied much of the shot and shell used by the Continental Army. In 1858 Rogers[64] reported the old openings as having been abandoned for many years but referred to the discovery a few years previously of a lode of magnetite averaging 6 feet in thickness. He also stated that within 100 feet of this lode there was a deposit of rich hematite ore.

The ore bodies that have been worked at the Durham mine are divisible into two groups, one on the northeast peak of the ridge known as Rattlesnake Hill, and the other on its southwest peak, known as Mine Hill.

The Mine Hill deposits were at first operated by open pits, short tunnels, and shallow shafts, the surface ore being a mixture of hematite and magnetite embedded in quartz. In 1859 a tunnel 2,000 feet long, known as the "new tunnel," was run south into the mountain just east of the village of Durham, encountering a blue ore consisting of magnetite and hematite, but this ore was poorer than that obtained nearer the surface. About the same time (1858) an opening was made in the south side of the hill. This was known as the "surface mine." The ore was red and consisted mainly of hematite. Work at this opening was suspended in 1862 and resumed in the fall of 1878, when a slope 200 feet long was sunk. A new shoot of ore was found that was 30 feet wide in places, 500 feet long, and 40 feet high at its maximum. Two other shoots were also encountered. One, 75 feet to the south, was 300 feet long and 12 feet wide in places, and the other, 100 feet to the north and cropping out, was 300 feet long and had a maximum width of 18 feet. This slope furnished the principal source of ore from the Durham Hills during the later portion of the nineteenth century.

[63] Most of the information concerning the Durham mine was furnished by B. F. Fackenthal, Jr., of Riegelsville, Pa., in a private letter dated August 1, 1924.

[64] Rogers, H. D., Geology of Pennsylvania, vol. 2, pt. 2, p. 715, Philadelphia, Pa., 1858.

The composition of the ore from the openings on Mine Hill is well exhibited by the analyses below, which were furnished by Mr. Fackenthal. They show that the ore was of bessemer grade and that it contained very little sulphur and a negligible amount of manganese. It was also low in titanium and in this respect was very different from the magnetic ores that were obtained from the Nickolas (1) and Kohl (2) openings, a short distance farther south.

Partial analyses of "red" ore from Mine Hill, Pa.

	1	2	3		1	2	3
Fe	53.63	43.15	36.37	Al_2O_3		2.14	3.33
SiO_2	20.39	36.76	39.15	MgO		1.47	1.22
P	.051	.005	.034	CaO		.00	.47
S	.076	.041	.230	H_2O+			1.64
Mn	Tr.	.00	.09				

1. Average of two analyses, 1869. Analyst, C. F. Chandler.
2. Sample from large dump of new tunnel at mine. Analyst, C. O. Lagervelt, Durham furnace, 1880.
3. Sample from dump of 3,000 tons at mine, 1885. Analyst, P. W. Shimer.

Many determinations of the phosphorus in the surface ore of Mine Hill showed a range between 0.008 and 0.067 percent.

None of the above analyses indicate the proportions of magnetite and hematite in the ore. The following analyses, however, show that hematite was far in excess of magnetite in the samples analyzed.

Analyses of average ore from Mine Hill, Pa.

	1	2		1	2
SiO_2	30.45	29.27	TiO_2	0.103	
Al_2O_3	.96	.41	MnO_2	.10	
Fe_2O_3	61.07	67.57	P_2O_5	.060	Tr.
FeO	5.66	1.53	S	.127	0.24
MgO	.17	.21	H_2O+	1.15	
CaO	.07	.59			
Na_2O	.00	Tr.		99.92	99.82
K_2O	.00	Tr.			

1. Sample from dump of 4,000 tons at mines, representing an average of the ore produced in 1885. Analyst, P. W. Shimer.
2. Red ore from underground workings at Mine Hill. Analyst, G. W. Maynard.

NOTE.—The ferrous and ferric oxides computed to metallic iron equal 47.15 percent in sample 1 and 48.48 percent in sample 2.

In sample 1 the figures indicate the presence of about 30 percent of quartz, 43 percent of hematite, 18 percent of magnetite, and 7 percent of limonite, on the assumption that all the water is in limonite; in sample 2 about 29 percent of quartz, 65 percent of hematite, and 4 percent of magnetite.

In the old openings on the surface at Mine Hill can still be seen exposures of a lean ore that may represent a poor quality of red ore similar to that analyzed by Maynard. In most places it is a mixture of hematite and milky quartz that looks uncommonly like vein quartz. The hematite is scattered uniformly through the quartz as little grains 3 millimeters or less in diameter, exhibiting here and there distinct crystal faces, many of which are marked by striations that suggest polysynthetic twinning, and as irregular veinlike streaks penetrating the quartz in diverging directions. Nothing else is seen in the hand specimen nor in the thin section except a rare smear of limonite. The quartz is granulated. Larger fragments with ragged contours are embedded in a fine-grained mosaic of quartz grains that appear to be intercrystallized. The larger grains are crossed by strain shadows, but the small ones forming the mosaic are entirely free from all forms of optical distortion. Here and there the mosaic penetrates the larger quartz grains as little veins and fills cracks in the hematite particles. It is not probable that material as lean as this was ever used as ore, because of the great difficulty of separating the hematite from the quartz, and yet it is evident from the size of the holes left on the surface of the hill that considerable ore must have been obtained from some of the pits. A few specimens found in the old dump heaps suggest that there were in the quartz large lenses of hematite containing only a small amount of quartz. It may be that the ore came from such lenses.

The quartz-hematite aggregate that is now exposed constitutes a quarry wall that looks not unlike the face of a joint plane. Its general appearance suggests a huge vein mass, or mass of pegmatite, but as its contacts with the neighboring rocks cannot be seen its relations to these rocks can only be surmised.

Other phases of what is believed to be the same geologic mass have been found in several test pits dug on the south slope of the hill on the side of the road from Monroe to Durham. These test pits were about one-third of a mile southwest of the open pits or quarries on the hill, but they are now completely filled. The ore collected from their dump heaps is a medium-grained gray and white rock, in some places massive, in others slightly schistose, and in still others porous and drusy. Little irregular cavities occur here and there through the rock, and from their walls project little crystals of quartz and hematite. These cavities suggest very strongly the "caves" or "pockets" in the gem-bearing pegmatites of Maine. The ore is an aggregate of little grains and crystals of hematite in a white material which in some specimens is granulated milky quartz and in others is a mixture of milky quartz and a very fine-grained mass of soft white barite. In some specimens the material is exclusively barite, the quartz being restricted to a few small glassy grains scattered through the finely granular white barite mass.

In the specimens characterized by a white schistose groundmass the quartz is all mosaic. Tiny veins of limonite cut through it, and scattered through it are small irregular masses of the same mineral.

In those specimens in which barite is an important component the sulphate occurs mainly as envelopes of small grains surrounding the hematite and the remains of corroded quartz grains. These quartz grains have extremely irregular outlines, and many of them show strain shadows.

An analysis of a specimen of the ore containing barite by Dr. D. F. McFarland, of the chemical department of the University of Illinois, showed 4.77 percent of quartz, 81.74 percent of Fe_2O_3, and 13.80 percent of $BaSO_4$. The only suggestion concerning the origin of this ore that occurs to the writer is that the quartz-hematite mass is in the nature of a crushed pegmatitic quartz vein and that the barite is a later introduction into the pore spaces of the crushed rock and along fracture cracks between the grains of its quartz mosaic and the larger quartz grains and hematite crystals. The barite may have come from Newark beds, the northern contact of which with the gneisses, is now at a fault about 1 mile south of the mine.[65]

The Rattlesnake Hill deposits are more like those occurring in the gneisses elsewhere in the Highlands than the deposits of Mine Hill. They are essentially lenses of intermingled magnetite and hematite that occur in veins striking and dipping with the enclosing gneisses.

Operations on Rattlesnake Hill began in 1851 in an open cut on the top of the hill, near its center. Two years later a tunnel was driven from its north slope, about 200 feet above Durham Creek, cutting two shoots of ore striking about northeast and dipping southeast. The first was called the Rattlesnake vein, and the second, above it, the Back vein or South vein. A slope was then opened on the dip of the Rattlesnake vein, levels were run, and the ore was stoped from the vein, which ranged in thickness from 2 to 50 feet with an average of 12 feet.

In 1854 another tunnel, known as the Hollow tunnel, was driven from the east slope of the hill, starting 8 feet above the creek. It was abandoned 8 years later after a pocket of ore that had been intersected had been removed. In 1878, however, another tunnel was driven 75 feet south of the abandoned tunnel and was called by the same name. At a distance of 500 feet from its entrance the Back vein was reached, and from this point the tunnel followed the vein, which ranged in width from 6 inches to 10 feet. A crosscut into the footwall disclosed the Rattlesnake vein 175 feet beyond. Ore was mined from the two veins until the mine was closed, in 1906. In addition more or less ore was taken from several openings south of the Durham property, but the quantity was not great.

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[65] Bayley, W. S., A peculiar hematite ore on the tract of the Durham mine, Durham, Pa.: Econ. Geology, vol. 7, pp. 179–184, 1912.

The ore from the veins on Rattlesnake Hill was more nearly like that of the magnetite mines in New Jersey, but differed from it in the presence of more hematite, as will be seen from the analysis quoted below. It was all of bessemer grade.

Analysis of ore from Rattlesnake Hill, Pa.

[Sample from mine dump of 2,000 tons, August 1885. Analyst, P. W. Shimer]

SiO_2	25.84	TiO_2	0.30
Al_2O_3	2.22	P_2O_5	.096
Fe_2O_3	56.73	S	.105
FeO	11.50	MnO	.10
MgO	.82	H_2O+	1.00
CaO	.16		
Na_2O	.28		99.881
K_2O	.73		

The metallic content of the sample was 48.65 percent of iron, and the mineral components were about 18 percent of quartz, 35.5 percent of magnetite, 31.5 percent of hematite, 6 percent of feldspars, some limonite and chlorite, and very small amounts of other minerals.

All the ore obtained from the Durham mines was comparatively lean but was low in phosphorus and sulphur and therefore was admirably adapted for use in mixtures with other ores to produce mill iron of unusual strength and for making pig iron for bessemer steel. When the mine was abandoned there was still abundant ore available, but the cost of mining was so high that it was not profitable to work. Since the Durham furnace was demolished in 1912 the conditions for the profitable working of the mine have been even more unfavorable than they were in 1906, as transportation cost would have to be added to mining costs before the ore could reach a market.

There is now no opportunity for studying the relations of the ore bodies to the surrounding rocks, as the pits and the exposures were destroyed by the mining operations. Moreover, there are in the literature no descriptions of the mine nor any reproductions of the mine maps except the map by T. B. Brooks that was published in 1868,[66] and this is based on data so doubtful as to be of little value. There is no reason known why the Rattlesnake Hill deposits should not be regarded as similar in origin to the magnetite deposits in the Highlands of New Jersey. The reason for the high content of hematite is not known.

In addition to the magnetite and hematite mined on the Durham property some limonite was taken from an opening at the northeast base of Rattlesnake Hill, but it was not of commercial importance. (See Orchard mine, p. 87.)

[66] Cook, G. H., Geology of New Jersey, p. 332, Newark, 1868.

South of the nontitaniferous ore veins of the Durham tract is a vein of titaniferous ores, which is referred to on page 77.

Barton, Kaiser, West End, and Swayze mines.—Most of the other mines in the gneiss areas of the two quadrangles present no unusual features. Their deposits are similar to those in the gneisses of the Raritan, Passaic, and other quadrangles in New Jersey. Those on the east side of the Delaware River have been described in the report on the iron mines of New Jersey, to which reference has repeatedly been made; consequently they need not be discussed at length here. It is sufficient to remark that most of the openings were in thin veins or in lean ore bodies, and therefore only a few were developed to any great extent.

At the Barton mines (24) several shafts and pits were opened on the east slope of the ridge south of Oxford Church, in a vein striking N. 80° E. and dipping vertically, and at the Kaiser mine (25), about a quarter of a mile northeast of the Barton, a shaft was driven on a vein 11 feet thick, of which only 5 feet was good ore. At both places the ore was too lean to ship. At the Kaiser mine a concentrator was built, but after operating a short time was abandoned as unprofitable.[67]

Apparently the most promising prospect for the future development of a mine is in the vicinity of West Portal, N. J., where the Bethlehem or Swayze mine (15), to the east, and the West End or Turkey Hill mine (14), to the west, seem to be on two veins 60 feet apart, extending with minor interruption all the way from the east end of the Swayze to the west end of the Turkey Hill locations, a distance of 3 miles. At both mines the ore was of bessemer grade. There is no record of the size of the ore body at the Swayze mine, where both veins were worked, but at the Turkey Hill mine, where only the western vein was worked, this is reported to have ranged from 6 to 40 feet in width. Its strike was N. 70° E. and dip 60° S. It was developed through a length of about 4,500 feet, but to a depth of only 300 feet. The ore seen on the dumps was fine grained. It contained hornblende, brown mica, and thin veins of calcite.[68] Analyses of the ore from three shafts showed results varying between the following limits:[69] Fe, 30.45 to 52.48 percent; S, 0.013 to 0.126 percent; P, 0.000 to 0.006 percent. It is estimated that the total amount of ore shipped from the two groups of mines was about 450,000 tons.

Titaniferous magnetite mines.—As early as 1892 Fackenthal[70] called attention to the fact that the ores of the southermost belt of

[67] New Jersey State Geologist Final Rept., vol. 7, p. 233–234, 1910.

[68] Idem, pp. 294–295.

[69] 10th Census U. S., vol. 15, p. 162, 1886.

[70] Fackenthal, B. F., Jr., Titaniferous iron ores in the blast furnace: Am. Inst. Min. Eng. Trans., vol. 21, p. 278, 1892.

magnetite mines in the Highlands of New Jersey and the Durham Hills in Pennsylvania are characterized by a titanium content much higher than that of most of the ores in other parts of these districts. Beginning at the northeast end of the belt the mines in New Jersey and the percentage of titanium dioxide in their ores are as follows: Naughright, near Chester, 6.40 to 7.50 percent; Johnson Farm, near Glen Gardner, 8.97 percent; Church or Van Syckle, near Van Syckles, 9.82 percent to 15.05 percent; Bloom Farm, near Little York, 4.7 percent; Hager, near Spring Mills, 7.02 percent. Fackenthal includes in the list also the Cramer mine, on Schooley Mountain, with ore containing 9.8 percent of TiO_2, but this is about 6 miles north of the line between the Hager and Naughright mines and cannot be regarded as being on the same belt. Moreover, near the line there are some openings from which ore has been taken that is reported to contain but little titanium, and distant from the line others in which the ore is strongly titaniferous. There is therefore no well-defined belt to which the titaniferous ore is limited, though there is a larger proportion of magnetite deposits containing notable amounts of titanium near the south border of the Highland area than elsewhere.

The Hager (5) and Bloom Farm[71] mines are in the Easton quadrangle. On the extension of the line in Pennsylvania are two more openings. The ore of one on the Kohl property (2), about a mile southeast of Durham village, contains 5.95 percent of TiO_2, and that of the other, on the Nicholas property (1), about 2 miles southwest of Durham, contains 2.86 percent of TiO_2.

HEMATITE

MINE OPENINGS

The only points at which hematite has been reported in the area under study are at the Mine Hill openings of the Durham mine (IV) (p. 71); at the Titman shaft (III), near Bridgeville, N. J.; at the Marble Mountain or Fulmer mine (II), on the east side of the Delaware River 1½ miles north of Phillipsburg, N. J., and on the Wolf farm (I), at the southwest end of Musconetcong Mountain, across the river from Monroe, where a few boulders of an ore like the quartz ore of Mine Hill (p. 71) were found scattered over the ground.

Marble Mountain mine.—The Marble Mountain or Fulmer mine (II) was opened in 1860, reexplored in 1880, and again explored in

[71] The precise location of the Bloom farm is not known. One report places it 1 mile north of Little York and another 1 mile west of the same village. The latter location is probably correct, as the opening was described as being at the foot of Musconetcong Mountain.

1886. It is reported that over 1,000 tons of good ore was mined, but no record that any of it was shipped has been found. The whole top of the west end of the ridge is cut by shallow pits and trenches, and a short tunnel penetrates the hill from the west near its summit. At the largest pit, 500 feet northeast of the tunnel, the ore was estimated to be 11 feet thick and to dip about 15° SE.

To the south of the ore pits there are yellow and light-purple schists, some of which are very quartzose, others talcose, and others fine-grained and dense like rhyolites. In one or two places hematite replaces the dense rock locally, forming nodules or rounded masses or disks that grade into the rock in all directions. In other places the schists are impregnated with hematite, and at several places distinct bands of hematite, like veins, cut across the structure of the schists. To the north the schists are replaced by quartzites and quartzitic conglomerates very similar to the conglomerates at the Andover, Simpson, and Cedar Hill mines, and here and there interlayered with the quartzose rocks are thin beds of a very soft black schist that may represent an old shale. It is reported that impure limestone was also associated with the ore.

So far as can now be determined the ore is merely a portion of the quartzite more ferruginous than elsewhere, the hematite occurring in the interstices between the quartz grains.

The Franklin limestone occurs north of the quartzite-schist series and under it on the bank of the river, and in the river channel are exposures of beds that are apparently squeezed arkoses and crystalline siliceous rocks, which at places seem to be sheared into talcose phases. All these rocks are described on pages 26–31 as belonging to the Pickering gneiss. The rocks near the mine are believed also to be a part of the Pickering, the talcose schists being perhaps metamorphosed limestones or highly calcareous sandstones or shales, although it is recognized that some of them may be mashed volcanic rocks. The source of the hematite is unknown. It is conceivable that the iron was furnished by a pegmatite like that which was mined at the Durham mine for the "red" ore (see p. 71), and that the ferruginous material thus made available replaced the cement of the sedimentary beds and some of the embedded components. Much of the talcose schist in the vicinity of the mine is probably a metamorphosed limestone, as it is talc nearly free from sand.

Titman prospect.—The ore at the Titman shaft has been referred to as being like that at the Marble Mountain mine. The opening was in a "gray slate" lying between the gneiss and the Kittatinny limestone. Nothing can now be seen at the location except a dump heap of slate fragments, gray schist, and pegmatite. The ore, which was found only in small quantity, was in the slate. There are no exposures of any rocks but gneiss in the vicinity, so that no conjecture as to the character and origin of the ore is of any great value. From the nature of the rocks seen in the dump it appears likely that the ore was a small deposit in a fault plane. The "slate" is plainly a sheared rock, but whether this was a gneiss or a phase of the Hardyston quartzite cannot now be determined. It is hard to believe that the ore was like that at Marble Mountain.

LIMONITE

MINE OPENINGS

Before 1880 the mining of limonite, "brown hematite," or "brown iron ore," was an important industry in the Delaware Water Gap and Easton quadrangles. The last mine that exploited limonite as an iron ore was the Shoemaker, near Belvidere, N. J., which operated until 1911. At this time all mining of limonite for ore ceased, but a little of the mineral is still being raised at a small shaft south of Easton, Pa., for use as a paint pigment.

The ore occurs in the Kittatinny limestone, usually near its base, where it is in contact with the underlying Hardyston beds or with gneiss. At some places, however, it is found near the top of the formation, and at other places at other horizons. In the two quadrangles under discussion the deposits that have been worked were very close to the contact with the Hardyston quartzite and at some places in fault zones.

The principal mines on the New Jersey side of the river were as follows:

- Shoemaker, on Buckhorn Creek 2 miles south of Belvidere.
- Fitz, about a quarter of a mile northeast of the Shoemaker mine.
- Roseberry, on the east slope of valley, 1 mile northeast of the Shoemaker mine.
- Rapp, Carpenter, Riegel, Reese, and Boyer, 1¼ miles south of Carpentersville.
- Silver Hill exploration, three-quarters of a mile south of Springtown.
- Hamlen, on Lopatcong Creek 2 miles east of Phillipsburg.
- Thatcher, or Stewartsville, 2 miles east of Stewartsville.
- New Village, or Cline, a quarter of a mile northwest of New Village.
- Broadway, at the base of Musconetcong Mountain, 1½ miles east of Broadway.
- Wean, on Musconetcong Mountain, a few rods south of the west entrance of the Lehigh Valley Railroad tunnel.
- Slack, on Musconetcong River 2½ miles northeast of Bloomsbury.
- Hazard, 1¾ miles west of Asbury.

Of these, the Shoemaker, the Roseberry, the mines near Carpentersville, the Hamlen, and the Thatcher mines were the most productive.

On the Pennsylvania side of the river an almost continuous series of pits flanked the north base of Morgans Hill, south of Easton, and extended all the way to the west margin of the Easton quadrangle. Most of them took their names from the owners of the land on which they were located, but a few were operated by others than the landowners and received distinctive names. As all the pits were abandoned many years ago, they have been so completely overgrown that their sites can no longer be identified. A few dump heaps of rotted rock are all that remain to remind one of the activity of former years.

The pits on the road running along the north side of Morgans Hill, beginning with the easternmost, were the Thomas Richard, Thomas Messinger, George Leibert,[72] James Hess, Widow Lewers, George Leibert,[72] Glendon Iron Co.,[73] John Woodring, Miss Miller, Joseph Sampson, Sampson & Sitgreaves, Heckman Estate, Adam Hahn, and Glendon Iron Co.[73] It is not known that any of these were very productive, although in the aggregate they yielded considerable ore. One other opening is a few hundred yards west of the junction of the road skirting the north base of Morgans Hill and the road crossing the hill. This is now being operated by the C. K. Williams Co. for pigment and kaolin. It cannot be identified with any of the old openings but is very close to those that were on the Sampson land. This mine is referred to further one page 85.

On the south side of the west end of Morgans Hill were other pits of the Glendon Iron Co., and a mile farther east, at the end of the little embayment of Hardyston quartzite, were several pits on the land of William Hahn. These evidently produced little if any ore.

Bordering the gneiss to the west and southwest were the openings of Dan Boyer, Jacob Crawford, Mary Brotzman, Joseph Brotzman, three more pits on the land of Mary Brotzman, and two pits on lands of Mrs. Thomas.

At the base of the north slope of Bougher Hill were the Ivy and the Raub & Lerch pits, and near the end of the limestone embayment north of Raubsville was a single pit on the land of Charles Walters.

All these pits except the Walters pit were at or very near the contact of the Hardyston quartzite and the Kittatinny limestone. A few were in the quartzite near the contact, but most of them were in the limestone. The Walters pit was in the limestone not far from a fault between the limestone and schist. It was never productive.

There were also a few openings on the north side of Rattlesnake Hill, but only one was of any economic importance. This was the Orchard mine, which furnished some ore to the Durham furnace.

72 Two pits under same name.
73 Two pits under same name.

OCCURRENCE OF THE ORE

The limonite occurs in very irregular shaped layers, or flat lenses, following the general direction of the contact planes between the gneiss and the Paleozoic rocks. The ore bodies are separated from one another by barren rock that is very much decomposed, or by ferruginous clay, through which are scattered small masses of compact and fibrous ore nodules and geodes. The ore bodies are mixtures of porous, earthy nodules, stalactites, masses of ocher, and lenses and nodules of chert. In many places small veins of limonite occupy joints and fault cracks in the neighboring rocks, and fragments from these rocks are intermingled with the mixture, which is cemented by compact limonite. The boundaries of the deposits are extremely irregular, and in places the ore extends along bedding planes and joint cracks for considerable distances beyond the main mass of the deposit.

CHEMICAL COMPOSITION

The brown iron ore as mined consists of nodular masses and small fragments of compact limonite mixed with different proportions of ocherous earth, sand, and small particles of various rocks. Commercially it is distinguished as rock ore, comprising the lumps that may be picked by hand from the natural ore, and wash ore, which is the fine, more clayey portion that constitutes the greater part of most deposits. This was freed from its impurities, which are lighter than the ore, by washing in a current of water.

The ore as shipped ranged in content of iron between 35 and 57 percent, in phosphorus between 0.006 and 1.6 percent, and in sulphur between 0.00 and 4.5 percent. Silica and manganese were present in nearly all the ores, but titanium was lacking.

The three analyses below give a fair idea of the character of the ore as shipped. No. 1 shows the composition of a dense fibrous nodule from the Rapp mine, near Carpentersville, and No. 2 that of selected brown nodules from the ore of the Shields mine, at Beatyestown, in the Raritan quadrangle. No. 3 is the analysis of wash ore from the Shields mine.

Analyses of brown iron ore

	1	2	3		1	2	3
SiO_2	4.90	3.36	19.24	K_2O	0.00	0.02	1.46
Fe_2O_3	81.15	82.01	60.99	P_2O_5	.114	.246	.588
Al_2O_3	.33	.76	4.72	SO_3	.049	.024	-------
MnO	1.54	.38	1.81	H_2O-	.58	1.08	.52
MgO	.04	.01	.70	H_2O+	10.71	11.86	8.88
CaO	.12	.00	.34				
Na_2O	.03	.09	.10		99.563	99.84	99.348

1, 2. New Jersey State Geologist Final Rept., vol. 7, 1910.
3. 10th Census U. S., vol. 15, p. 176, 1886. Contains also NiO, 0.06; CoO, 0.04, CO_2, 0.06; pyrite, 0.077: C 0.110.

The sample of ore from the Shields mine, which is representative of the soft ore of the district, contained about 24.91 percent of insoluble material with the following composition: SiO_2, 19.24; Al_2O_3, 4.06; Fe_2O_3, tr.; MgO, 0.48; CaO, 0.07; Na_2O, 0.03; K_2O, 1.02; total, 24.90. This is the composition of a feldspathic sand. Besides the sand the wash ore contains small quantities of organic matter, pyrite, apatite, carbonates, and probably some iron phosphate, as there is an excess of 0.385 percent of P_2O_5 over that required to make apatite with all the available soluble CaO revealed by the analysis. Moreover, the analysis of the nodules from the Shields ore shows 0.246 percent of phosphorus and no lime, and the only metal present with which the phosphorus is likely to be combined is iron.

ORIGIN

The limonite ores in New Jersey are believed to have the same origin as the limonites found in similar geologic associations throughout the Southern States. The principal source of the iron probably lay in the limestones and shales associated with the ore bodies and the rocks which originally overlay them but which have disappeared through erosion. A small quantity of the metal was also furnished by the pyrite occurring in the adjacent gneisses and their included magnetic ores. The ferruginous solutions, which may have contained carbonates or sulphates, were oxidized by contact with the alkaline waters resulting from the solution of the limestone, and iron hydroxides were precipitated.

Ferruginous solutions containing sulphates or carbonates, on mingling with alkaline waters resulting from solution of limestone or on coming in contact with the limestone itself, would tend to precipitate iron hydroxide, or possibly iron carbonate which would alter to the hydroxide.[74]

These iron hydroxides accumulated in any crevices through which the water passed, forming masses of comparatively pure and compact limonite. Where the cracks were in limestone this rock was gradually removed along their sides, and in its place limonite was deposited. The insoluble impurities in the limestone remained and were mixed with the limonite, the whole forming a typical ore deposit. Where the filled fissures were in the Hardyston quartzite the calcareous cement of the rock alongside the vein was replaced,

[74] Informal communication from G. F. Loughlin. Meigen, W., Beitrage zur Kenntnis des Kohlensauren Kalkes: Naturf. Gesell. Freiburg Ber., vol. 13, p. 76, 1903, as cited by Adolph Knopf in A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, 1918, p. 107. Burchard, E. F., Iron ores in the Brookwood quadrangle, Alabama: U. S. Geol. Survey Bull. 260, 1904, pp. 333-334.

and a mass of sandy limonite containing nodules of limonite resulted.[75]

The tendency of ore solutions to follow contacts is explained by the fact that contacts between different rocks offer favorable conditions for the percolation of ground water. This is especially true of fault contacts along which the rocks have been crushed and sheared.

Chance[76] has suggested that all the limonite deposits in the Paleozoic rocks throughout the eastern United States are due to the oxidation of pyrite. His explanation of the origin of the limonites from pyrite differs from those previously proposed in that he does not suggest that the pyrite was introduced as veins in previously existing rocks, but believes that it was deposited with the sediments forming the rocks in which the ores are now found. He believes that the present ores are the oxidized remains of pyrite deposits practically in place and that they are underlain by undecomposed pyrite. In other words, Chance suggests that they are gossans overlying sedimentary pyrite beds. He concludes that percolating water could not carry the ore into the clays with which they are associated, because these clays are impervious, "for to permit such deposition it would be necessary to provide a porous or soluble stratum, such as limestone, which by dissolving might provide space for the deposition of ore and open channels for the circulating waters. But there is no evidence of the presence in these slates (clays) of any such stratum." He thinks that the deposition of the ore by circulating water is shown to be impossible, because there are particles of ore "which are sealed and isolated in clay impermeable to water," and moveover this clay "is frequently white and quite free from iron, which could not well be the case if for long periods it had been saturated with water heavily charged with unstable salts of iron." He therefore dismisses the theory and proposes his alternative one.

Chance's story, however, still needs percolating water to oxidize the supposed pyrite beds, and he describes a mine 270 feet deep in the lower levels of which "the ore is fissured and the fissures are usually watercourses through which water may readily be carried down to the zone below, in which oxidation is probably now progressing at or below permanent water level." Intermixed with the ore in the deeper workings some very pure carbonate ore was found, but no pyrite was noted "either in the form of isolated masses or lumps (sulphur balls) or incased in ore."

In other parts of Pennsylvania, outside the area under discussion, Chance observed a pyrite sandstone containing about 84 percent of

[75] Compare Bayley, W. S., General features of the brown hematite ores of western North Carolina: U. S. Geol. Survey Bull. 735–F, pp. 160–163, 1922.

[76] Chance, H. M., A new theory of the genesis of brown hematite ores, and a new source of sulphur supply: Am. Inst. Min. Eng. Bimonthly Bull., No. 23, p. 791, 1908.

pyrite and a series of rocks consisting of layers of clay containing much finely divided pyrite and "pure pyrite slime, frequently showing not more than from 3 to 5 percent of foreign matter." These occurrences are supposed to represent the original conditions in the Easton quadrangle. As the writer has not seen these two occurrences and they are outside the area now being considered, he is not warranted in expressing any opinion as to their bearing on the origin of the Easton and Phillipsburg limonites.

It is clear from Chance's discussion that the general shapes and attitudes of the brown iron ore deposits in the Easton quadrangle are as characteristic of veins as of beds and that, in spite of the impermeability of clay, there has been passage of water through them or through the rocks of which they are the decomposition products. Moreover, in the South, where there are better opportunities for observing similar ores in place, these ores are unqestionably vein masses.

In the same series in which Chance's paper was printed Catlett[77] calls attention to the fact that the reason mining for the brown iron ores has extended only to shallow depth is "that the surface material represents an accumulation from the breaking down and collecting of the ore which formerly reached a much higher level. With increasing depth comes a decreasing thickness of valuable material." He also thinks that the great number of concretionary forms of the ore, the existence of masses "showing the evidence of secondary solution and deposition now taking place, such, for instance, as the part replacement of quartzite derived from the underlying beds," and the improbability of an original deposition of iron sulphide of sufficient magnitude to yield the present limonite deposits throw serious doubts on Chance's theory. Catlett is inclined to believe that the immediate source of the iron was a carbonate, and cites the mines at Vesuvius, Va., and near Cartersville, Ga., where limonite is known to pass into the carbonate. Moreover, he believes that the association of manganese with the valley limonites is naturally explainable on the assumption that the original deposit was a carbonate, as manganese is usually deposited[78] as carbonate and rarely as sulphide, and iron and manganese carbonates are isomorphous and have therefore a strong tendency to crystallize together.

Catlett concludes his discussion with a description of the Oriskany ores of Virginia, which are very much like the valley ores in Pennsylvania and New Jersey. He states that the Oriskany slates are

[77] Catlett, Charles, Discussion of paper by H. M. Chance: Am. Inst. Min. Eng. Bull. 24, p. 1179, 1908.

[78] Penrose, R. A. F., Jr., Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, p. 569, 1891.

strongly pyritiferous and that the waters flowing from them carry large quantities of iron as sulphate or carbonate. When these waters reach the sandstone underlying the slates they pass through it to a series of limestones carrying interbedded chert. As the strata are folded and highly tilted, the heavily charged ferruginous solution passing into the slates mingles with waters from the limestone, and as a result iron carbonate is precipitated. This later oxidizes to limonite and gypsum, and the gypsum, being soluble, is carried away. The most favorable plane of deposition is the contact between the limestone and the sandstone.

In Pennsylvania and New Jersey the favorite places of deposition for the limonite are near the contact of limestone and quartzite or slate, but any one of these rocks may be above. Both slates and quartzites are permeable to solutions along their schistose planes, the quartzite being perhaps more easily permeable because of the shattering it underwent during the deformation that gave it the high dip which it nearly everywhere exhibits. The clays that are so commonly associated with the ore and the chert that is frequently found with it are the result of the decomposition of the slates, quartzites, and limestone. The clay was leached during the process of decomposition and is therefore now devoid of iron except such as was originally present in it as veins of insoluble limonite, which during the erosion process were broken down into fragments. The geodes were probably in the limestone, and the pieces of stalactites were in the more open portions of the veins. Stalactites and nodules of limonite are common in the Cambrian limonite veins in North Carolina.[79]

LIMONITE MINES

Williams shaft.—The only active mine on the limonites of the district during the summer of 1923 was a small operation by C. K. Williams & Co. (21), of Easton, Pa. A few hundred yards west of the junction of the Philadelphia and Hellertown roads, at the north foot of Morgans Hill, in Pennsylvania, is a shallow shaft through which is obtained a small amount of limonite and some kaolin. Most of the limonite is the soft ocherous variety and is used for paint. With this are many hard nodules, which are picked by hand and saved as ore. The limonite layer, which is said to be not more than 8 feet thick, lies immediately on a footwall of gneiss. Above it is a layer of kaolin about 20 feet thick, and above this the ordinary blue Kittatinny limestone. The kaolin is thinly laminated and gritty and here and there contains small nodules of pure kaolin that suggest altered pebbles. It is probable that the kaolin is a decomposed feldspathic layer in the Hardyston quartzite. It is said by the miners to grade

[79] Bayley, W. S., General features of the brown hematite ores of western North Carolina: U. S. Geol. Survey Bull. 735, pl. 5, *D*, 1922.

upward into the limestone and downward into the ore. The contact between the ore and gneiss, however, is said to be sharp.

Shoemaker mine.—The Shoemaker mine (32) [80] on the west slope of Scotts Mountain, at the mouth of the valley of Buckhorn Creek, in New Jersey, was formerly one of the most productive of the limonite mines in the district. It was opened in 1888 and operated almost continously until October 1911, when it was abandoned. A tunnel and several shafts had developed a vein at least 600 feet long, ranging in width between 2 and 40 feet and having a dip of about 45° SE. The tunnel, which was driven southeastward into the base of the mountain, penetrated 35 feet of dark-green talcose slate, 300 feet of light-buff clay slate, and 3 to 12 feet of flint or chert and ended in ore 4 to 12 feet thick, dipping 50° SE. The hanging wall was a body of very white clay, resembling that associated with the ore at the Williams shaft, referred to above. This white clay may represent a bed of feldspathic Hardyston quartzite lying between the ore and the gneiss of the mountain. The flint underlying the ore may be a remnant of the Kittatinny limestone, and the light-buff clays decomposition products of this rock. The flint was probably originally a chert layer in the limestone. The dump at the shaft, in 1910, contained many pieces of ore composed of sharp-edged fragments of a yellowish slate cemented by limonite, forming a breccia such as occurs in some places between the mountain gneisses and the valley sedimentary rocks. The ore probably lies in a fault zone in the Hardyston beds, into which it was carried by water that found its easiest course downward in the fault rubble lying against the crystalline rocks.

In all the descriptions of the attitude of the ore reference is made to its dip to the southeast. This apparent dip under the gneiss is probably due to creep. The ore is on the steep slope of the gneisses, where, together with all the rocks on the slope, it has gradually moved downward into the valley to the northwest as decomposition proceeded and disintegration ensued. At the Roseberry mine (30), on the same slope, about a mile northeast of the Shoemaker mine, this is evidently what has happened, as the dip of the ore layer, which near the surface was about 45° SE., at a depth of 80 feet suddenly changed to the northwest. Where the change occurs the ore impinges against the gneiss, which lies to the southeast, and below this point follows the contact plane between the gneiss and the Cambrian beds, which normally trends northwest.

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[80] Most of the statements concerning the Shoemaker mine are taken from the description of this mine in the report on iron mines and mining in New Jersey (New Jersey State Geologist Final Rept. vol. 7, p. 54, 1910).

The ore of the Shoemaker mine was a nonbessemer soft limonite, mixed with clay, sand, and slate. Much of it required washing before shipment. The two analyses quoted below illustrate its quality.

Analyses of brown hematite from Shoemaker mine, near Belvidere, N. J.

	1	2		1	2
Fe	51.42	48.20	CaO	1.68	0.99
P	1.048	.267	MgO	.18	.72
Mn	.17	----------	SiO_2	8.85	10.38
Al_2O_3	3.86	2.09			

1. Shipment, 1899.
2. Ore raised in 1906.

Orchard mine.—The Orchard mine (1)[81] was on the Durham furnace property near the northeast base of Rattlesnake Hill, in Pennsylvania, 800 feet north of the Hollow tunnel. The mine was opened in 1849 and operated for some years, until the ore was supposed to be exhausted. In 1876, however, it was reopened, and a small additional amount of ore was recovered. The ore mined in 1876 was of bessemer grade, though it contained more phosphorus than the hematite and magnetite of the Durham mine. A partial analysis gave Fe, 46.71 per cent; P, 0.39 percent; insoluble components, 7.36 percent.

Other limonite mines.—The other openings in New Jersey that produced brown hematite ore have been sufficiently described in the report on iron mining in New Jersey, to which repeated reference has been made. At the mines near Carpentersville (41) the ore is reported to have been in a vein between a north wall of limestone and a south wall of gneiss, from which the ore was separated by clay containing streaks of quartz and layers of chert nodules, suggesting that the clay is decomposed limestone or decomposed calcareous Hardyston quartzite. At the Thatcher mine (34) were immense lumps of compact limonite lying in an "elongate pocket" or veinlike mass running through the center of the deposit, which consisted mainly of small lumps and fine granules of limonite mixed with ocher, clay, and sand. Many of the larger lumps were hollow and partly filled with clay, coarse quartz sand, and scattered small fragments of siliceous hematite. None of the other deposits exhibited any noteworthy features.

The pits and other openings in the Pennsylvania portion of these quadrangles have not been described in detail. They have been so long abandoned that nothing can now be seen that will furnish any evidence as to the manner of occurrence or origin of the ore.

[81] Information concerning the Orchard mine was furnished by B. F. Fackenthal, Jr., in letter dated August 1, 1924.

There is, however, no reason to believe that the deposits differ in any respect from the similar deposits in New Jersey.

PIGMENTS

Much of the wash ore from the limonite mines in Pennsylvania and New Jersey has been used as pigment, but so far as known no opening of any considerable size has been made for the purpose of obtaining either ocher or umber. The old stock pile at the Ahles or Pequest mine was washed in 1920, and the settlings were dried, roasted, and ground and sold as umber. During the operation of the mine much of the wash ore was used as ocher. This material, comprising about one-third of the ore raised, was a mixture of limonite, pyrolusite, and clay. The remaining two-thirds of the ore was magnetite. Ocher is now being mined at the Williams shaft, south of Easton (see p. 85), but not in large quantity. In earlier years ocher is known to have been shipped from the Hamlen and Wean mines. It was probably also shipped from many of the other mines in the two quadrangles, as the deposits in nearly all places contained more soft, clayey limonite than hard lumps of the mineral. There is unquestionably an enormous quantity of ocher in the district, but most of it will have to be washed before it can be utilized.

Other materials produced in the district for use as pigments are kaolin and mineral pulp. Both of these are referred to below under other heads.

ZINC

So far as known the only zinc ore that has been produced in the Easton district was obtained during exploratory work near the Raub mine (28), about a mile southwest of Buttzville, where sphalerite occurs as veins and disseminated particles in the Franklin limestone. Attempts were made to open a mine on the deposit at a point a few rods southwest of the junction of the roads to Hazen and Oxford, now obliterated by the Edison quarry opening.

The explorations, which were begun in 1875, were undertaken in the search for iron ore. In 1883 they were directed toward the development of a zinc mine. At this time two openings were made on opposite sides of the road to Hazen, and a large quantity of rock was raised. It is reported [82] that the sphalerite occurred in two veins 5 feet apart. One of the openings was a shaft in the sinking of which about 200 tons of rock was raised. It is stated that this rock contained an average of 12 percent of zinc, and a few tons of richer material that had been picked from the poorer rock contained as

[82] New Jersey Geol. Survey Ann. Rept. for 1884, p. 109, 1885.

much as 50 percent of the metal. Sphalerite is also reported to have been found in the southwestern shaft of the Raub mine.[83]

Before the opening of the Edison quarry a dark hornblendic rock, which later work in the quarry proved to be a small dike, was associated with the limestone on the south side of the Hazen road. This dark rock was said to contain sphalerite. No sphalerite is noticeable in the dike in the quarry, although the limestone in the vicinity of this dike and others contains considerable pyrite and fluorite. (See p. 24.)

In 1937 a large blast at the northeast end of the quarry disclosed fine-grained yellowish-brown sphalerite and associated galena that had replaced limestone in small masses and networks of streaks. A few tons of this mineralized rock had been segregated on the dump, but the pile of blasted rock in the quarry was still too big to permit a search for the rock in place.[84]

The conditions that have been described as existing here are essentially similar to those at the Sulphur Hill mine, near Andover, N. J., except that the magnetite is much less abundant. In both places the source of the zinc was probably the magma that formed the dikes.

KAOLIN

The only kaolin now being produced in the district is that being taken from the Williams shaft, where it occurs between the ore and the blue Kittatinny limestone. Kaolin is known also to occur elsewhere in the same relation to the ore, but whether it is at any place pure enough for use in pottery making without thorough washing is not certain, and so far as is known it does not occur in sufficient quantity within any small area to warrant the construction of washing plants. The small amount that has been produced has been used for paint.

Kaolin of the same type and of similar origin has been worked at several places in Pennsylvania, where it is associated with limonite as in the Easton area. Ries [85] has given a list of the occurrences in southeastern Pennsylvania and has summarized descriptions of them by Hopkins and Stose, and Moore [86] has given an account of similar clays in central Pennsylvania. In both areas the kaolin is at the contact of Cambrian sandstone and Ordovician limestone, as it is also in the Easton area, and is associated with limonite. In all the places described the clay is believed to be derived from siliceous beds near the base of the limestone series. Moore states that in

[83] New Jersey Geol. Survey Ann. Rept. for 1879, p. 83, 1879.

[84] Informal communication from G. F. Loughlin and D. F. Hewett, U. S. Geol. Survey.

[85] Ries, H., Bayley, W. S., and others, High-grade clays of the eastern United States: U. S. Geol. Survey Bull. 708, pp. 82–91, 1922.

[86] Moore, E. S., idem., pp. 92–99.

central Pennsylvania the bulk of the clay comes from the borders of abandoned iron mines, and that there are all gradations between clay and ore and between clay and sand. He also notes[87] that

> the association of the clay and iron is probably due to the fact that the iron has been carried in solution by underground water and concentrated in areas where beds of argillaceous dolomite are associated with the sandstones. * * * The circulating waters readily remove the soluble constituents, depositing the iron oxide through replacement of the dolomite and leaving the insoluble argillaceous materials as clay.

Moore concludes with reference to the central Pennsylvania clays that although the deposits are generally associated with the limonite and most of them have been discovered in working the iron, it is believed that other clay-bearing areas may be found.

Most of the kaolin appears to have been shipped to steel works. Some of the clays are white enough in their unburned condition to be used as paper filler after thorough washing but are probably not satisfactory for the manufacture of white ware, as they do not burn white. They are, however, used in sagger manufacture and, when washed, might be used by the paint and rubber trade. The clays from southeastern Pennsylvania have been used for paint; in the manufacture of portland cement, paper, and plaster board; and in steel works. As the white clays of the Easton district are identical in character and in method of origin with those described by Hopkins, Stose, and Moore, it is probable that they can be used for the same purposes, if they can be found in large enough quantity to pay for the cost of washing. Clay deposits occur in nearly all the old limonite mines, but they have never been developed.

This association of limonite and kaolin resembles the association of the same minerals at the Dragon Iron Mine in the Tintic district, Utah, and of limonite, kaolin, and $ZnCO_3$ at Leadville, Colo. At both places water descending through altered (pyritic) igneous rock had replaced limestone with kaolin and red or brown iron oxide. The iron oxide in turn replaced the kaolin, which was driven along as an advance guard or partial "casing" to the iron oxide. The process of replacement is discussed in detail in reports on these districts.[88]

MARBLE AND SERPENTINE

The Franklin limestone has been exploited in various portions of the Highlands as a building stone, as an ornamental stone for interior decoration, as a flux, for stucco and terrazzo, as mineral pulp, and for the manufacture of portland cement, lime, and hard plaster.

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[87] Moore, E. S., op. cit., p. 93.

[88] Informal communication from G. F. Loughlin, U. S. Geol. Survey. Lindgren, Waldemar, Loughlin, G. F., and Heikes, V. C., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, 1919, pp. 262–265. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U. S. Geol. Survey Prof. Paper 148, pp. 261–271.

Only four quarries in the marble and its associated rocks were operated in the district during 1923. The material from them was being used for portland cement, flux, stucco, terrazzo, mineral pulp, and, incidentally, for interior decoration.

FLUX AND PORTLAND-CEMENT ROCK

The Franklin limestone at present is mainly quarried for flux and for the manufacture of portland cement. It is produced mainly at the large quarry (*18–21*) of the Edison Portland Cement Co., in the Pequest area about 2 miles northwest of Oxford, N. J. The quarry is a large opening about a quarter of a mile long and nearly as wide and between 70 and 85 feet deep. During the working season it produces daily about 1,400 tons of rock, which is shipped by a spur of the Delaware, Lackawanna & Western Railroad, mainly to cement plants. The general character of the rock in the quarry is described on page 24. About 70 percent is available for use. The waste consists of the material of the dikes that penetrate the limestone and the darker portions of the limestone that are usually high in magnesia.

Eight analyses that present fairly well the run of the quarry are quoted below. They were furnished by Mr. H. E. Keifer, chemist of the Edison Portland Cement Co., in 1923.

Representative analyses of rock from the Edison Portland Cement Co.'s quarry

	1	2	3	4	5	6	7	8
SiO_2	1.64	3.50	1.12			4.38		
$CaCO_3$	93.22	91.44	95.81	91.74	95.92	88.33	82.45	91.44
$MgCO_3$	2.16	3.30	2.16	1.99	2.39	2.32	3.61	5.81

The average content[89] of the rock utilized by the Edison Co. in 1923 was as follows: SiO_2, 1.52 percent; $Al_2O_3+Fe_2O_3$, 1.02 percent; $MgCO_3$, 2.25 percent; $CaCO_3$, 95.16 percent.

The amount of good cement rock still remaining in the Pequest area is large, but not every portion of it will yield rock as well adapted to the making of cement as that in the Edison quarry, as some beds contain as much as 20 percent of $MgCO_3$.

STONE FOR BUILDING AND INTERIOR DECORATION

The Franklin limestone has been utilized to a slight extent locally as a building stone, but no commercial quarries have been opened in it within the two quadrangles for the sole purpose of supplying building stone. Some material that was used for building was taken from old quarries in the Pequest area and near Roxburg and at Lower Harmony, but none has been quarried in recent years. There

[89] Letter from F. A. Sinclair, assistant secretary, dated November 27, 1923.

is an abundance of good building stone in the quarries on the road running northwest from Hazen, but it probably has a greater value as cement rock, and moreover it is more expensive to shape than the blue Kittatinny limestone.

Rock for interior decoration has been quarried at the old Warne quarry (*15*), on the Delaware River 2½ miles north of Phillipsburg, at the Verdolite quarry (*12*), on the opposite side of the river about 1½ miles north of Easton, and at the old Schweyer quarry (*5*), on Bushkill Creek at the southwest end of Chestnut Hill.

At the Warne quarry, now operated by the Rock Products Co., of Easton, the rock is a mixture of serpentine, tremolite, talc, calcite, and dolomite (see p. 29). Most of it was formerly ground for mineral pulp, but much of the more compact material obtained was sawed and polished and used for decorative purposes. The favorite variety was a mottled mixture of light and dark serpentine, besprinkled with grayish or pinkish dolomite grains and streaked with seams of fibrous calcite containing embedded asbestos fibers. The production of decorative stone by this quarry was, however, never very large, most of the energy of the operators being directed toward the production of mineral pulp until recently. Now the rock is used mainly for terrazzo and stucco. In 1922, however, some material was used for interior[90] work in the Easton Trust Building, at Easton, Pa.

The Verdolite quarry (*12*), operated by C. K. Williams & Co., is the largest and most active of all the quarries in the Franklin limestone. It includes the old Sherrer and Fox quarries, besides the original Verdolite quarry. For some time its principal products were a very pure light-green serpentine and a pink and light-green mottled rock composed of dolomite and serpentine, both of which were sold in the rough for use as wainscoting, mantels, and decorative columns. The waste was ground to mineral pulp. The decorative stone was limited in quantity and was soon exhausted, or the cost of its production became greater than its value, and its extraction ceased. All the lighter-colored portions of the quarry rock that are measurably free from mica are now ground.

The Schweyer quarry was opened for decorative material exclusively. The rock was a dark- and light-green mottled serpentine. A mill was built, and a large amount of material was sawed into slabs and polished, but the adventure was not a success, and the place is now abandoned. If the quality of the rock may be judged from the slabs left at the mill, it may be inferred that failure was due to the scarcity of material compact enough to bear handling. Much of the

[90] U. S. Geol. Survey Mineral Resources, 1922, pt. 2, p. 309, 1924.

rock is jointed, and nearly all of it is so sheared that the comparatively thin slabs are fragile.

At two other points decorative material has been produced, but never in large quantity. At the Weygadt pit (*14*), half a mile north of the Verdolite quarry, a pearl-gray dolomite containing light and dark yellowish-green, waxy-looking, translucent serpentine was quarried for a short time, but the quantity developed by the operation was too small to warrant continued work. Many years ago at the Klein quarry (*17*), Lower Harmony, rocks very like those at the Verdolite quarry were sawed into slabs and worked into monuments, and the quarry refuse was burned to lime.

At other places along the belt of limestone on the south side of Chestnut Hill handsome varieties of serpentine and marble are present, but the rocks are so badly sheared and jointed that it is difficult to find any masses of compact material large enough to warrant working.

MINERAL PULP

Most of the mixed serpentine-talc-tremolite rock quarried from the belt of Franklin limestone skirting the south side of Chestnut Hill has been ground and used as mineral pulp. The favorite variety for this purpose consists of talc and light-green serpentine, which furnishes a white or very light colored powder. The varieties composed largely of dark serpentine are less favored because they yield a tinted powder. The pulp produced near Easton, according to Peck,[91] was employed as a pigment, as an adulterant in cheap soaps, as fillers in paper and rubber, and in the manufacture of wall plaster.

The practice was to crush the rock to the size of pea coal and then feed it to French buhrstones, the lower one of which revolved. The rock was ground to an almost impalpable powder, which was sized by bolting and then bagged for shipment. Peck lists 16 quarries in the strip, at most of which rock for mineral pulp was quarried. With the exception of the old Warne quarry, in New Jersey, and the Verdolite quarry, in Pennsylvania, all have been abandoned. Two new quarries have been opened in recent years, but not for pulp rock.

STUCCO, TERRAZZO, AND ROOF GRANULES

The four quarries operating in 1923 on the Chestnut Hill belt of Franklin limestone were engaged largely in the production of crushed rock for use as stucco, terrazzo, and roof granules. The rock was crushed to ⅜-inch size for stucco and smaller sizes for terrazzo and

[91] Peck, F. B., The talc deposits of Phillipsburg, N. J. and Easton, Pa.: New Jersey Geol. Survey Ann. Rept. for 1904, pp. 163–185, 1905.

roof granules, and the waste and dust were ground to powder and sized by 150- to 300-mesh sieves for mineral pulp.

At the quarry of the Rock Products Co., on the east bank of the Delaware River (formerly Warne's quarry), the rock used for stucco, etc., is a fine-grained light-green mixture of serpentine and talc with a little carbonate that is not sufficiently schistose to exhibit any marked tendency to break in any one direction. The color varies, of course, with the shade of the serpentine and its proportion in the mixture. It may be very light green, medium dark green, or some shade of greenish gray. The total production of the quarry in 1925 was between 2,000 and 2,500 tons.

Another quarry (7) operated by the same company is northwest of Easton, well up on the slope of Chestnut Hill. Here there are two openings, from one of which is obtained a white marble spangled with mica, and from the other a dark-green fine-grained massive igneous rock. (See p. 41.) Both rocks are crushed and sold for stucco and terrazzo, the igneous rock under the trade name "Evergreen." About 1,500 tons of both are produced annually.

The Verdolite quarry of C. K. Williams & Co., on the west shore of the Delaware River, is the largest in the district. It has produced rock for all the purposes for which the serpentine marble of the district has been employed, but at present it is devoted to the production of stucco, terrazzo, and mineral pulp.

The fourth active quarry in the district, a new opening by Williams & Co., on the southwest side of Bushkill Creek about 1½ miles west-northwest of the square at Easton, is not much more than a prospect. It has been opened on a very compact, hard fine-grained serpentine (see p. 42), cut by silicified asbestos veins, that will furnish an excellent dark-green stucco and terrazzo.

LIME

The purer varieties of the white limestone have been burned for lime at a number of points in the district, but so far as known only for local use. Reference has already been made to the burning of the waste of the quarry at Lower Harmony. Old limekilns are still recognizable at the various quarries on the road between Hazen and Buttzville, and ruins that were probably kilns have been noted elsewhere. The Franklin limestone in this district will probably never be used for lime, because the purer varieties are comparatively rare, except in the Pequest area, and there it is of greater value as cement rock.

TALC

At nearly all the quarries opened in the Chestnut Hill belt of Franklin limestone there is more or less talc, but for the most part it is mixed with serpentine, tremolite, and carbonates. It is a valuable ingredient of the mineral pulp. At a few places, however, where shearing has been marked, the talc schist is sufficiently pure to be sold as ground talc.

At present no talc is being marketed as such. Formerly it was obtained at the old Warne quarry, in New Jersey, and from the old openings near Bushkill Creek, in Pennsylvania. Here the talc appears to exist in largest quantity, perhaps because the rocks are more profoundly sheared than elsewhere. Talc was taken from the old opening between the active quarry of the Rock Products Co. north of Easton and the old Schweyer quarry on the bank of Bushkill Creek. The best material, however, came from the two open pits in the small limestone area north of the west end of Chestnut Hill. On the old dump can still be found many pieces of white foliated talc that is almost free from grit.

At both the openings where the best talc was found the limestone is intruded by an igneous rock (see p. 41), but it is doubtful if this had any influence on the origin of the talc except perhaps to furnish a buttress against which shearing was localized.

ASBESTOS

Chrysotile asbestos occurs in shearing planes in the marble at the Verdolite quarry, on the Delaware River, but not in large enough quantity to be of commercial importance. It forms long fibers of good quality. (See p. 35.)

MICA

From time to time there have been attempts to obtain mica in commercial quantities from the pegmatite dikes that are so common in the Byram and Losee gneisses, but without success. Most of the pegmatite contains more or less mica but, so far as known, nowhere is the mineral present in sufficient quantity to be profitable to mine.

PRODUCTS OF THE PALEOZOIC FORMATIONS

The economic products of the Paleozoic rocks, in addition to limonite, which has already been discussed, are building stone, limestone for lime, and cement rock.

The Kittatinny limestone, which is of Upper Cambrian and Lower Ordovician age, has furnished excellent building stone. In the area of the Easton and Delaware Water Gap quadrangles it is a blue or bluish-gray well-bedded massive rock that withstands weathering well and that breaks fairly easily into quadrangular blocks which are readily built into walls and foundations. Many old structures scattered through the area testify to its excellence as a satisfactory building stone. The same rock has also, in the past, furnished abundant material suitable for burning into lime, but as it contains from 15 to 20 percent of magnesium carbonate, the lime made from it has been used mainly as a soil sweetener.

Rock for the portland-cement industry is furnished by the upper beds of the Jacksonburg limestone (Middle Ordovician). These beds are dark fossiliferous, more or less shaly limestones, some layers of which contain 95 percent of calcium carbonate, and calcareous shales. One belt of this rock extends northeastward from Carpentersville to New Village, furnishing material for the Vulcanite and the Edison Portland Cement companies, and another belt from a point near the northwest corner of the Easton quadrangle northeastward through Martins Creek and Belvidere and some miles beyond. The rock in the southern part of this belt has been extensively utilized by the Alpha Portland-Cement Co., but the greater part of the belt remains undeveloped.

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